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Lipid and Energy Utilization as Affected by Dietary Lysophospholipids in Swine

양돈에서 사료내 유화제 첨가가 지질 및 에너지 이용성에 미치는 효과

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이 논문을 농학박사 학위논문으로 제출함

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Summary

The objectives of these experiments were 1) to evaluate the effect of dietary lysophospholipids (LPLs) on growth performance of weaning and growing pigs 2) to investigate the effect of different energy and LPL supplementation on the productivity of late gestating and lactating sows 3) to estimate nutrient digestibility and nitrogen retention in growing pigs.

Experiment 1. Energy sparing effects of dietary LPL in weaning and growing pigs

This study was conducted to evaluate energy sparing effect of lysophospholipid (LPL) on growth performance and productivity from weaning to growing pigs. A total of 140 crossbred ([Yorkshire × Landrace] × Duroc) pigs with averaging 7.3 ± 1.62 kg of initial body weight were randomly allotted to one of four treatments based on sex and initial body weight according to randomized complete block (RCB) design in 5 replicates with 7 pigs per pen. The 2 × 2 factorial arrangement was used and the first factor was dietary energy levels (3,200 or 3,300 kcal ME/kg), and the second factor was supplementation of LPL (Supplementation levels: 0 or 0.05%). Experimental pigs were fed corn-barley-soybean meal based diets and feeding program was composed of three phases (Phase I, 0-2 week; Phase II, 3-5 week; Phase III, 6-10 week). In Phase I, improvements of average daily gain (ADG) and average daily feed intake (ADFI) were not affected by dietary

treatments. However, gain to feed (G/F) ratio was increased in low energy treatment (P=0.04) and tended to be higher when LPL was supplemented. In phase II (3-5 week), both dietary energy level and LPL supplementation had no effect on growth performance. In Phase III, increased ADG (P<0.01) and tendency of improving G/F ratio (P=0.09) were observed when LPL was added to diets. Supplementation of LPL improved ADG by 15% and 11% in 6-10 week and 0-10 week, respectively. As well supplementation of LPL improved G/F ratio by 20% in 6-10 week and 13 % in 0-10 week. The feed cost/weight gain was reduced when pigs were fed diets containing LPL during overall experiment periods except for Phase II. Consequently, this experiment demonstrated that LPL supplementation to growing pigs' diet can improve growth performance and productivity with reducing production cost of pigs.

Key words: Lysophospholipid, Energy level, Growth performance, Economics, Pig

Experiment 2. Effects of different energy and LPL supplementation in late gestating and lactating sows.

This study was conducted to evaluate the effects of different energy levels and LPL supplementation in sow diets from late gestating period to lactating period on the performance of sows and their progeny. A total of 60 F1 (Yorkshire × Landrace) sows at d 90 of gestation were assigned to 4 treatments, 15 replications

by CRD. Treatments were divided by dietary energy levels and LPL supplementation levels in factorial arrangements. First factor was energy level (3,300 kcal of ME/kg or 3,200 kcal of ME/kg) and second factor was LPL level (0 or 0.05%). There were no differences on body condition, WEI and ADFI in lactation sows. Rectal temperature of gestating sows (d 110) was increased by increment of energy level and LPL supplementation ($P<0.01$ and $P<0.01$, respectively). Although there was no difference in reproductive performance, interaction between energy and LPL supplementation was observed at parturition. High energy treatments (H1 and H2) showed higher number of total born and born alive while low energy treatments (L1 and L2) had lower number of total born and born alive (E×X, $P=0.06$ and $P=0.06$, respectively). Litter weight and piglet weight did not show any difference during lactation period, but litter weight gain tended to increase in high energy treatments ($P=0.06$). Dietary energy level or LPL supplementation had no influence on composition of colostrum and milk (21d). As dietary energy level increased, serum insulin level of lactating sows (21d) was increased ($P=0.03$). Glucose level was decreased by LPL supplementation at d 110 of gestation ($P<0.05$). There were no effects on IgG and IgA at 24 hrs postpartum, but LPL treatments (L2 and H2) showed lower IgG level than 0% LPL treatments in suckling piglets at d 21 of postpartum ($P<0.01$). In conclusion, there were no differences on reproductive performance and litter performance in their progeny although 100 kcal of ME/kg

was reduced in sow's diets. However, current study showed positive responses in number of piglets and litter weight gain at d 21 of lactation numerically as energy level increased (P=0.18 and P=0.06, respectively).

Key words: Energy, Lysophophospolipid, Sow, Reproductive performance, Litter performance.

Experiment 3. Effects of dietary LPL supplementation on nutrient digestibility in growing pigs

This experiment was conducted to evaluate the effect of dietary energy and LPL on nutrient digestibility in growing pigs. A total of 12 crossbred ([Yorkshire × Landrace] × Duroc) pigs with averaging 22.7±1.6kg were allotted to each treatment in an individual metabolic crate to collect feces and urine separately. Growig pigs' nutrient digestibility trial was conducted to evaluate the nutrient digestibility and nitrogen retention in completely randomized design (CRD) with 3 replicates. Treatments were as followed: 1) ME 3,200 kcal/kg, 2) ME 3,200 kcal/kg with LPL supplementation, 3) ME 3,300 kcal/kg, 4) ME 3,300 kcal/kg with LPL supplementation.

All other nutrients in experimental diet were met or exceeded the NRC requirement (2012). The experimental diets were provided twice a day every 07:00

and 19:00. There were no differences in digestibility of dry matter, crude protein, crude fat and crude ash. In addition, there was also no difference in nitrogen retention. However, the amount of fecal N tended to increase as dietary energy level increases (P=0.06). Although fecal N showed linear difference in this experiment, the current study represented that nutrient digestibility and nitrogen retention rate were not affected by different energy levels and LPL supplementation. Therefore, it is concluded that LPL supplementation and different energy levels did not affect nutrient digestibility of diets fed to growing pigs.

Key words: Growing pigs, Lysophospholipid, Nutrient digestibility, Nitrogen retention, Dietary energy

Contents

List of Tables

I. Review of Literature

II. Experiment I

III. Experiment II

IV. Experiment III

List of Figures

I. Review of Literature

II. Experiment I

III. Experiment II

List of Abbreviations

AOAC	:	Association of official analytical chemists
ADG	:	Average daily gain
ADFI	:	Average daily feed intake
AME	:	Apparent metabolizable energy
ATTD	:	Apparent total tract digestibility
BW	:	Body weight
BWG	:	Body weight gain
CCK	:	Cholecystokinin
CP	:	Crude protein
CMC	:	Critical micelle concentration
CWG	:	Choice white grease
FCR	:	Feed conversion ratio
FDA	:	Food and Drug Administration
HDL	:	High-density lipoprotein
HLB	:	Hydrophilic lipophilic balance
LDL	:	Low-density lipoprotein
LPL	:	Lysophospholipid
NRC	:	National Research Council
ME	:	Metabolizable energy
RCB	:	Randomized complete block

SAS : Statistical Analysis System

SSL : Sodium stearoyl-2-lactylate

USDA : United States Department of Agriculture

WEI : Wean to estrus interval

I. Introduction

Lipids and oils are very important dietary ingredients in animal production due to their high energy value (Bajao and Lara, 2005). And also other ingredients such as corn, wheat are being used to meet energy requirement in formulation. Therefore, dietary lipids have been considered as one of important sources to increase energy concentrations of swine diets with lower cost (Zhao et al., 2015). Even though we can increase the amount of lipid a lot in diets, the usage rate is limited in animal diet since fat digestibility is lower in most young animals (Carey et al., 1972). There are many fat sources which can be used in animal diets such as animal fats and vegetable oils. A research has been found that providing vegetable oils showed a positive effect on growth performance of weanling pigs, which is a possible effect caused by the high value of polyunsaturated fatty acids (Dove, 1993).

Energy is one of major cost components in diets for higher performing animals including piglets (Feedstuffs, 2013). Thus, lysophospholipid(LPL) could be supplemented to improve the digestibility of fat and thus improvement in energy efficiency (Zhao et al., 2015). The terms “fat and oil lipid” mean triglycerides which contain several fatty acids profiles without additional bounding to other organic compounds as glycerol and they are known as non-esterified fatty acids (World

Poultry Magazine, 1995). Lipid is considered as a major energy supplier for animals since they have the highest energy value among all the nutrients (Bajao and Lara, 2005). Jones et al. (1992) demonstrated that a decline in fat digestion is related to lipid characteristics and the amount of lipid content in the diet. The limitation of fat digestibility is controlled by many factors including ages, and various species also affect the lipid digestibility (Kussaibati et al., 1982). Because young animals are lack of production of natural pancreatic lipase and bile salt, they have some problem in lipid digestion (Marzooqi et al., 1999). Therefore, lipid digestion could be improved by adding LPL to the diet diet (Jones et al., 1992).

Improving lipid digestibilty is related with saving cost. Wilson and Bayer (2000) observed that feed cost makes up approximately 60-70% of the total production cost, and the energy itself takes up approximately 70% of total feed cost (Saleh et al., 2004). There are many approaches to reduce feed cost such as using LPL.

The addition of fats to the diet of weanning pigs has been reported to improve average daily gain and feed conversion ratio in a suckling period (Cera et al., 1990; Howard et al., 1990; Li et al., 1990). Previous reports showed that supplementation of emulsifiers could aid lipid digestibility and subsequently effect on growth performance in weaned pigs (Xing et al., 2004). Jones et al. (1992) also found that digestibility of lipid increased in a suckling stage after lecithin or

lysolechitin was supplemented in the diets containing soybean oil or tallow. However, Øverland et al. (1994a,b) didn't find any improvement in growth performance and lipid digestibility in weaning pigs with lecithin from soybean.

Therefore, the current research was aimed to investigate the effects of lysophospolipids supplementation as an emulsifier on nutrient utilization, blood metabolites and growth and reproductive performance in weaning, growing pigs and sows.

II. Review of Literatures

1. Lipids in swine diets

1.1 The lipid digestion and absorption in swine

The fat digestibility of young animals including piglet is not enough (Carey et al., 1972). There are many factors that affect fat digestion in young pigs (Kussaibati et al., 1982). Kitts et al. (1956) demonstrated that the limitaion of fat digestibility was influced by deficient pacreatic enzyme production in young piglet. Their result showed secretion of lipase gradually increased by the age of seven weeks. It implicates that increased lipolytic enzyme activity of pancreas may aid the hydrolysis of dietary lipid in young piglets (Kitts et al., 1956).

In general, ingested lipid is metabolized to release glycerol and free fatty acids by pancreatic lipase before absorption (Desouza et al., 2003). Hartman et al. (1961) compared the lipolytic activity of suckling piglets with that of piglets at one day after weaning. Results showed a reduction of lipase was observed at weaning but there was a gradual increase at 6 week of age. Additionally, Pond et al. (1971) observed that the amount of lipase secretion also increased as animal age grew. This

was consistent to Carey et al. (1972), who observed a lower concentration of lipase at 2 weeks of age and increased again thereafter at 4 weeks of age in nursing pigs.

Gall bladder plays a role in bile salt secretion which further influence on fat digestibility in swine (Desouza et al., 2003). The emulsifying characters from bile salts showed increasing the digestibility of fat by diminishing fat droplets and the effect of the lipase activated in the GI tract, decreasing fat particle size (Matias, 2015). Furthermore, bile salts have positively effect on formming a micellar phase in the small intestine for lipase to interact, which enhance digestibility of fatty acid in animal diets (Bayley and Lewis, 1963; Gurr and James, 1971).

Freeman et al. (1968) showed that the absorption of lipid was insufficiently occurred in the GI tract of young pigs with less bile salt. This was similar to the finding of Bayley and Lewis (1963), who found that the fat digestibility was improved when more fatty acids assimilated into the micelles. Use of LPL to increase fat digestibility was also reported by Augur et al. (1974) and Polin (1980), who observed that LPL addition could aid fat emulsification in young animals.

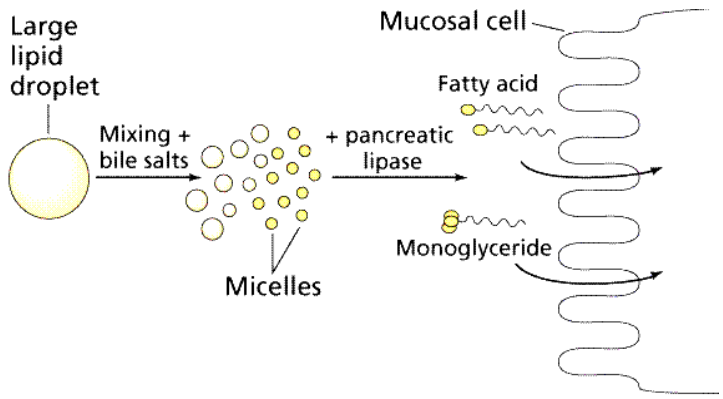

Figure1. Mode of action of the digestion and aborption of fat (Kemin Ind.)

1.2 Alterations of digestive morphology in piglets

Stress gives negative impact on intestinal and immune system of weaning pigs and also further detrimental effects on pig health, growth performance, and feed consumption especially in early stage of weaning (Campbell et al., 2013)

Small intestine is an important segment in the gastrointestinal tract for aiding nutrient digestion and absorption, controlling body homeostasis as well as exchanging ions and also it has a great impact on mucosal immune system (Carey et al., 1983). Post-weaning GIT disorders in swine have detrimental effect on altering the intestinal structure and morphological function of the GI tract by adapting enteric microbiota (Konstantinov et al., 2004b) and immunity (Stokes et al., 2004; Baileyet al., 2005).

After weaning, pigs are more susceptible to intestinal disorders, bacterial infections and diarrheoal occurrance (Lalles et al., 2007). It is established in many reports that sow's milk strongly influences on piglet growth rate because milk includes 30~40% lipid as a dry matter basis (Asplund et al., 1960; Perrin, 1955; deMan and Bowland, 1963). However, the disease could occur after directly fed exogenous diets (Perrin, 1963). It was resulted in decreased feed intake and growth performance from weaning stress or environmental factor. There was a consistent observation from previous studies that showed reduced feed consumption of pigs, which occured after 1 to 2 week weaning period (Mersmann et al., 1973; Okai et al., 1976).

An additional problem with young piglets is a low concentration of pancreatic lipase production (Marzooqi et al., 1999). Desouza et al. (2003) demonstrated that the digestibility of fat increased during a suckling period but the secretion of lipase was still lower in nursing period compared with growing pigs. It has been reported that the digestibility of milk fat significantly decreased by 65 to 85% just after weaning, which consequently affects energy deficiency of postweaning piglets (Liu et al., 2010). Thus, we have tried to meet the deficient energy during this period with various and selected fat sources (Sewell et al., 1965). However, the results are still controversial (Jin et al., 1998).

2. Strategies for improving fat digestibility in swine

2.1. Functions of endogenous bile salt on lipid digestion

The synthesis of bile acid occurs in the liver and the majority of bile salts are cholic acid (Nervi et al., 1988). This is put together in the liver with glycine or taurine (Donald, 1978). Water solubility increases and cellular toxicity of the bile salts decreases (Gaull and Wright, 1987; Borgstrom, 1974). The bile salts of pigs are normally conjugated with glycine (Alvaro et al., 1986).

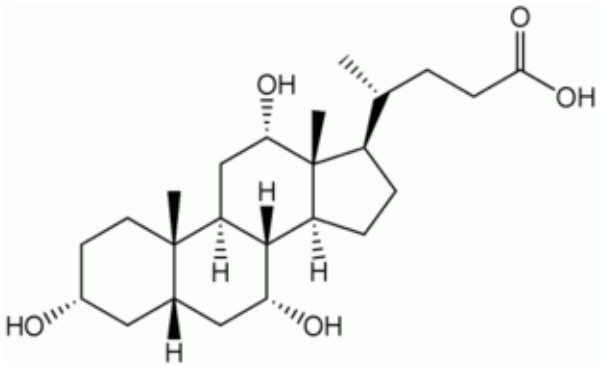

Figure2. chemical structure of cholic acid (Cell magazine 2012)

In general, phospholipid structure contains both hydrophilic and hydrophobic sides (Gaull and Wright, 1987). The hydrophobic side is responsible for fat emulsification (Nervi et al., 1988). The hydrophilic group of the bile salts plays an important role in the aqueous circumstance of the GI tract for better water-

lipid interface (Armstrong et al., 1968). The pancreatic lipase can spontaneously work for increasing the hydrolysis of triacylglycerol (Drackley, 2000). The bile salts act as a solubilizing material of lipase in the small intestine to increase the oil-water interface (Bauer et al., 2005).

Another function is regulating re-esterification of triacylglycerol from monoacylglycerol and fatty acids through the solubilization of these compounds and elimination from the site of lipase digestion (Holt, 1971; Northfield et al., 1973; Lowe, 2002). Patton et al. (1981) reported that the digestion and absorption of lipid was not completely done and required a length in the distal parts of the intestine without bile salts. Demarne et al. (1982) demonstrated that lipid absorption of rats depended on the amount of bile secretion from bile duct ligation. They also found a rapid reduction in apparent absorption of dietary lipids by 50% from it.

The final products of lipolysis are required bile salts in incorporation of dietray lipid to form mixed micelles for better absorption of dietary fats, monoacylglycerols and phospholipids (Holt, 1971).

The blened micelles plays as an important carrier to convey the lipolytic compounds from the small intestinal lumen to the absorption area, consequently fat emulsification is improved in the unstirred water layer of the intestinal microvillus membrane (Dietschy, 1978).

The micelles formation relys on amount of bile salt secretion and value of critical micellar concentration, which are important for a detergent to create micelles in an aqueous environemnt (Carey, 1983). Northfield and McColl (1973) and Heaton (1985) demonstrated that the secretion of bile salt is in the duodenum significantly increased up to 15 mmol/L and gradually decreased to 6 mmol/L thereafter. Additionally, it was detected that bile salt concentration of 10 mmol/L was lowered under 4 mmol/L in the ileum. Even though bile salts are not a major substance for dietary fat absorption, they have a great impact for fat digestion with providing proper conditions (Lowe, 2002).

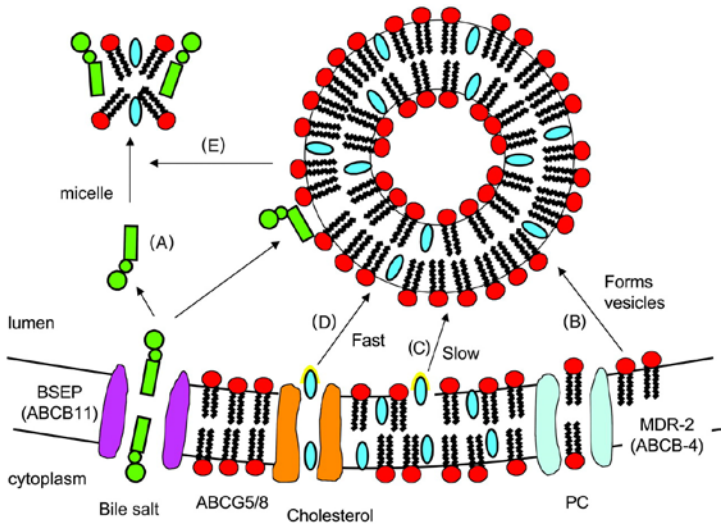

Figure3. The meachanism of bile salt in aiding lipid digestion (Donald M. Small PNAS 2003;100:4-6)

2.2. Various fat sources and their digetibility in swine diets

Various fat sources including tallow, vegetable oils are recognized as one of the most important raw materials since they contain higher energy value than others and they have approximately 2.25 times higher energy value than that of carbohydrates (Maynard et al., 1979). Generally, we recognize that the structure of fatty acids varies as the fatty acid profiles in the animal diet (Gebert and Messikommer, 2002). There are many kinds of available fat sources including lard, tallow, fish oil, corn oil, soybean oil, rapseed oil, palm oil and coconut oil. Most nutritionists of feedmills are prefering using fat sources from animals in pig diets since the animal fat sources contain better fatty acid profiles although their energy values are lower than those of vegetable energy sources (Zollitsch et al., 1997). Manuel et al. (2000) reported that lipid sources from vegetable contain much higher unsaturated fatty acids than lipid sources from animals so it can influence on pork quality related with fatty acids

Characteristics of fatty acids between animal lpid sources and plant lipid sources are very different chemically and physically (Gebert and Messikommer, 2002). Therefore, nutritional values also may be not same entirely among the fat sources. A few studies showed that the digestibility of various lipid sources was expressed with various results in swine diets as fat sources (Cera et al., 1989; Mendoza et al. 2014). Typically, fats from animals are less digestible compare with

fats from plants in young pigs (Cera et al., 1989). Jørgensen et al. (2000) observed that fat digestibility is not influenced a lot from various fat sources in grower and adult pigs except weaning baby pigs.

However, according to Lauridsen et al. (2007), significant difference of fat digestibility as various fat sources was not observed in their trials from weaning period to growing period. It's likely that there is clear relation between a rate of growth and a rate of fat absorption as various fat sources (Cera et al., 1989). Thomasson (1956) tried to segment a few various fat sources as their absorption rates. According to Thomasson (1956), butterfat showed the best absorption rate and next one was corn oil, followed by cottonseed oil, tallow, coconut fat, soybean oil, and sunflower. Steenbock et al. (1936) reported that lancid lard showed the most excellent absorption rate in rate more than cottonseed oil and coconut oil. However, when we review their studies regarding fat absorption, the fat digestion rates as various fat sources have not been consistent in young pigs.

As an energy source, most feedmills are using mainly plant oils and animal fats the most in feed industry (Bajao and Lara, 2005). Although fat absorption rates are various in accordance to fat sources, there seems to be no big difference in fat absobption rate between lard and tallow (Thrasher et al., 1959; Sewell and Miller, 1965; Liebbrandt et al., 1967). But, according to Liebbrandt et al. (1972), they provided weaning pigs to select feeds which were included with lard

and other fat sources, after that the weaning piglets showed nearly double feedintake (28.73 vs. 15.76kg) in lard compared with those of other feeds containing various fat sources. Braude and Newport (1973) observed that the absorption rate of butterfat and soybean oil is better than that of coconut oil and significantly much higher than that of tallow in the basis of apparent digestibility in weaned baby pigs after d 2 of age from weaning. Freeman et al. (1968) also observed the digestibility of soy oil was higher than lard, howerer it's almost similar with coconut oil. Jacobson et al. (1949) made a conclusion that the young pigs had no enough ability to utilize various fat sources through their many trials.

Table 1. Fatty acids compositon of various fat sources

Fatty acid (%)	Fat sources[1]			
	Corn oil	**Soybean oil**	**Tallow**	**Fish oil**
C14:0	-	-	2.20	13.45
C16:0	11.34	7.24	22.98	27.22
C16:1	-	0.05	1.88	16.85
C18:0	1.14	2.81	28.73	4.74
C18:1 (n-9)	34.38	34.70	39.95	
C18:2 (n-6)	52.62	50.53	4.16	2.64
C18:3 (n-3)	0.52	4.66	0.11	2.40
C20:4 (n-6)	-	-	-	0.87
C20:5 (n-3)	-	-	-	15.51
C22:6 (n-3)	-	-	-	6.54
SFA[2]	12.48	10.05	51.71	31.96
MUFA[3]	34.38	34.70	39.95	9.78
PUFA[4]	53.14	55.19	4.27	27.96
n-6 PUFA	52.62	50.53	4.16	3.51
n-3 PUFA	0.52	4.66	0.11	24.45
PUFA/SFA	4.26	5.49	0.08	0.87

[1]Energy value **(**ME**)**: corn oil, 8,405 kcal/kg; soybean oil, 8,400 kcal/kg; tallow, 7,680 kcal/kg; fish oil, 8,135 kcal/kg.

[2]SFA = Saturated fatty acids.

[3]MUFA = Monousaturated fatty acids.

[4]PUFA = Poly unsaturated fatty acids

Source: Jung et al. (2003)

Choice white grease (CWG) is occasionally used as a commercial lipid source (Benz et al., 1988). When the calorierprotein ratio was kept consistent, pigs fed CWG showed better fat abosoption rate than those fed with no fat (Asplund et al., 1960). It is told that sometimes CWG is more possitive than pigs fed vegetable oil-supplemented diet regarding carcass yield (Benz et al., 1988). Yellow grease is widely used as an energy source in swine diets, which is commonly recognized as having a nutrient value as much as CWG (Seerley et al., 1964). One of previous studies showed that yellow grease was excellent energy source that affects energy, protein ratio in modern pigs (Clawson et al., 1962).

Table 2. Various fat sources and fat digestibility by ages

Paramater	Corn oil	Lard	Tallow
Fat intake, g/day			
Week 4	20.17	19.04	18.79
Week 5	33.1	35.88	38.04
Week 6	52.84	52.36	61.99
Week 7	**70.88**	**71.57**	**75.54**
Fat digestibility, %			
Week 4	78.96	68.12	64.82
Week 5	80.48	71.76	72.36
Week 6	88.82	83.55	81.82
Week 7	**88.79**	84.9	82.48

(Cera et al., 1990)

According to USDA report (2015), total amount of vegetable oil production was 286 billion pounds in 2014 and continousely has increased from the mid of 1990s and still is going up. Among vegetable oils, total palm oil amount takes up 30% from total world vegetable oil production followed by soybean oil (28%), rapeseed oil (15%), sunflower oil (9%) and other vegetable oils (20%). When we take a look at the production amount of palm oil by countries respectively, Indonesia is the most palm oil production country and second one is Malaysia (Laure`ne F. et Al., 2010).

In Korea, feed millers prefer to use animal fats due to availability and economical price. However, they prefer to use vegetable oils in piglet diets due to better digestibility of vegetable oil compare to animal fats.

2.3. Effects of exogenous lipase on lipid digestibility

Pancreatic lipase level is much lower until young piglets get nourishment by suckling (Gu and Li, 2003). Once they start suckling, pancreatic lipase increases relatively, in particular between 2~ 4 weeks of age (Cranwell, 1995 and Liu et al., 2001). Corring et al. (1978) researched pancreatic enzyme activity in the piglet GI track from 0 to 8 weeks of age and discoverd that the pancreatic activity increased as piglets aged. Cera et al. (1990b) found that pancreatic lipase activity in nursing piglets increased rapidly from day 2 to 35 and weaning at d 21 brought about diminishing it for minimum 3 days postweaning and then increased linearly.

According to Kitts et al. (1956), pancreatic activity begins to increase from birth to seven weeks of age as times goes by. Lipase activity is also important for the main role in the beginning of acidification as a free fatty acid is more suscepive to acidification than the same fatty acid in a triacylglycerol compound (Dierick, 2002).

Exogenous lipases are also supplemented to amimal diets to improve fat digestibility (Frobish et al., 1970). According to Dierick et al. (2004), the lipase supplement increased the digestibility of some fatty acid (C6:0, C14:0) and Dierick et al. (2004) also observed that the apparent ileal DM and AFD digestibility was increased by lipase supplementation significantly. Furthermore, the apparent ileal DM (72.4 vs 77.6%) and protein (79.6 vs 83.9%) were improved slightly. In contrast,

Bee et al. (1996) reported a negative effect of lipase supplement on the digestibility of lard (82.7 vs 70.9%), but the fat digestibility was significantly increased (40.1 vs 65.3%) with adding dry fat

In poultry, Marzooqi and Leeson (1999) conducted broiler trials to evaluate the effect of lipase supplement with mixed oil (animal 4%, vegetable 8%) on broiler performance. Their results showed an increase in ME and apparent fat digestibility in lipase supplemented groups. However, side effects such as lower feed consumption and lower BW gain (P<0.01) were shown with the lipase treatments. Also similar results were observed when they increased the amount of lipase supplement on treatments more than double compared with first trial. The reason of decreasing feed intake and growth rate was that CCK (cholecystokinin) might cause contamination of lipase, which is secreted with the response of duodenum and jejunum (Marzooqi and Leeson, 1999). Meng et al. (2004) also reported that lipase supplement didn't show any positive results on broiler performance and the digestibility of various nutrients. Although there are many researches regaring exogeneous lipase, it is still controversial about it.

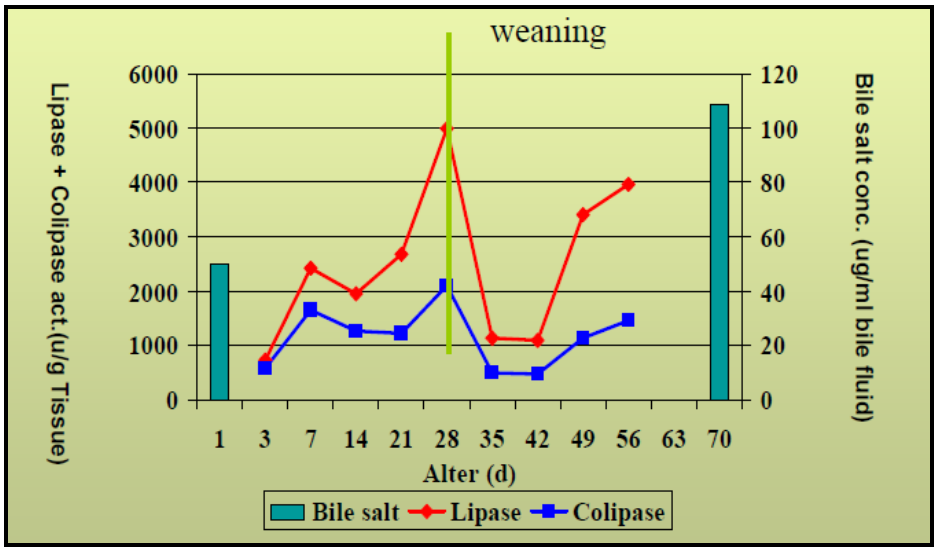

Figure 4. Development of bile salts and lipase secretion in young pigs (Gobert & Hedemann 1999)

2.4. Effects of exogenous emulsifiers on fiber digestibility

Martin and Farrell (1998) reported the effect of adding lipase on improving fat digestion with high level of wheat based diet. Nevertheless, animal performance was not improved with dietary lipase supplement. Marzooqi and Leeson (1999) also failed to prove the effect of lipase supplement on broiler performance because of the contamination of the lipase with CCK. However, there was a research that fat digestibility could be improved by supplementation of exogenous phospholipase (Carey et al., 1983). Santos et al. (2004) also observed adding phospholipase increased fat digestion. It is commonly recognized that fat

digestibility can be improved with endogenase in wheat-based diets through diminishing viscosity and microbial fermentation in the gut (Steenfeldt et al., 1998; Meng et al., 2004).

Endogenous phospholipase A_2 (PLA) induces the hydrolysis of the ester bond at sn-2 position of glycerophospholipase (GPL) and forms lysophosphatidylcholine (LPC) and fatty acid（John et al., 2008**)** and then in the lumen the fatty acids are absorbed (Carey et al., 1983). LPC (Lysophosphatidylcholine) plays a very important role in emulsification of water-insoluble lipids (Homan and Jain, 2001). Lipid digestion is more complicated compared with other nutrients and first step of lipid digestion begins from emulsification. One of the most important amphiphile molecules is LPC, which works for stabilizing microdroplets of triglycerides, cholesterol, and other nonpolar dietary fats that are insoluble in the intestinal contents with aqueous environment (Matsumoto et al., 2007). And the capacity of the enterocyte to transport absorbed lipids into the circulation also affected by LPA, because cellular phosphatidylcholine synthesis regulated by the hydrolysis of phosphatidylcholine in the luminal contents can be influenced by its capacity (Carey et al., 1983).

In addition to it, a natural secretin-release activity that causes the discharge of pancreatic secretion and bicarbonate in the duodenum may be induced by PLA and so the digestion and absorption of other various nutrients may be

increased by it (Chang et al., 1999). Thus, it is considerd that exogenous lipase might work with a similar way to endogenous phospholipase A2, and the counter effects of NSP by promoting forming micelles of triglycerides, cholesterol, and other nonpolar fats could be relieved by it (Carey et al., 1983). However, there are few available reasearches conducted regarding mode of action of lipases on fiber digestion.

3. Effects of exogenous LPL on lipid digestibility

3.1 Sodium stearoyl-2-lactylate

Sodium stearoyl-2-lactylate (SSL) is one of the hydrophilic emulsifiers and kinds of sodium salt of long chain carboxylic acid including two ester linkages (Choi et al., 2012). SSL is synthesized chemically with lactic acid, stearic acid and sodium hydroxide and lactic acid is mostly derived from bacterial fermentation (Niels et al., 2004). We may get stearic acid from animal fat or the hydrogenation of unsaturated vegetable oils (Choi et al., 2014).

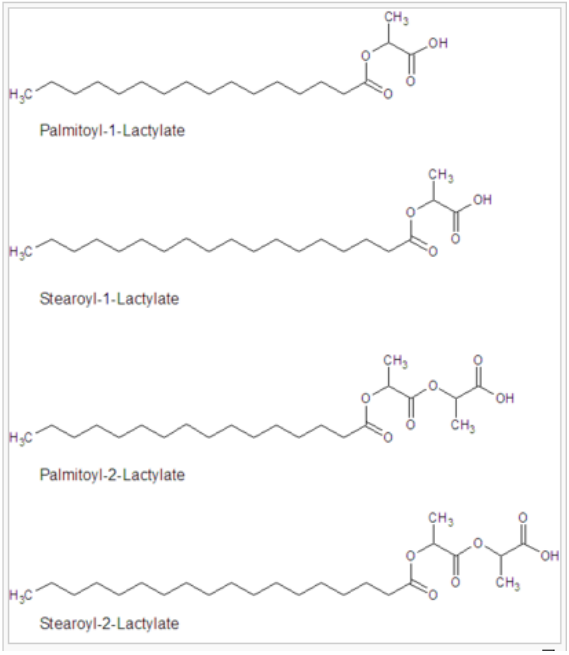

Figure 5. Structures of lactylate species (google, 2016)

SSL is used in various fields as emulsifier (Manohar et al., 1999; Gomez et al., 2004), whipping fator (Kelly et al., 1999) and conditioning factor (Armero et al., 1988) expecially in food industries. The HLB value of this hydrophilic LPL is apporximately 20, so we classify it as an Oil-Water type emulsifier (Choi et al., 2014). Moon et al. (2012) reported SSL supplementation in the postweaning diets showed improvements remarkably on growth performance, and blood profiles and nutrients digestibility (especially crude fat digestibility) with 5 % increase approximately in SSL treatments compared with no SSL treatment. According to Moon et al., (2012), the exogenous emulsifier(SSL) supplementation in the diet

worked to increase lipid digestibility, thus enhenced fat digestibility showed positive effect on HDL : LDL ratio subsequently.

In poulty, Choi et al. (2014) also observed that SSL treatment with low energy diet also showed better performance compared with SSL non-supplemented treatments. As the dietary exogenous hydrophilic LPL level increased, linear response in abdominal fat was found but except it other measurments regarding carcass trait did not show differences in organs and carcass comparison among treatments (Choi et al., 2014). Even though there were no differences in nutrient digestibility among treatments, SSL contributed to growth performance in the 75 kcal of ME/kg reduced treatments compared with control diet in this experiment (Choi et al., 2014).

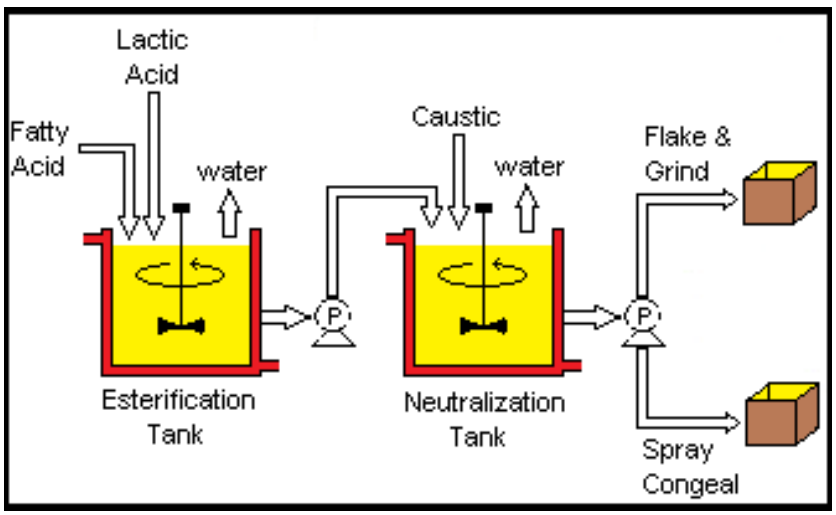

Figure 6. The process of SSL

3.2 Lecithin

Generally, lecithin is a complex mixture of phosphatides since they are by-products obtained in the oils refining process by hydration and drying subsequently (Sylvia et al., 2010). Most lecithin is obtained from soybean oil mainly because it contains a lot of phosphatides (Øverland et al., 1993). However, lecithin also can be gained through corn, cottonseed, rapeseed, rice, sunflower, sometimes even eggs and animal fats (Willem et al., 2008). The most interesting components of lecithin are the phospholipids due to their emulsifying properties and thus we use lecithin commonly in food processing since it has its own characteristics such as dispersing, stabilizing, and emulsifying ability (Jones et al., 1990a).

Lecithin contains various colors from light brown to dark reddish brown (A Chapter from the Unpublished Manuscript, History of Soybeans and Soyfoods, 1100 B.C. to the 1980s). Crude vegetable oils contain a lot of lecithin which includes the gummy material and is removed by degumming (Van et al., 1985). Soybeans are the most important source of commercial lecithin until now and lecithin became one of the most important by-products of the soy oil because of its many applications in food industries (Van, 1978). The three main phosphatides in soya lecithin complex mixture named "commercial soy lecithin" are phosphatidyl, phosphatidyl ethanolamine, and phosphatidyl inositols (Alejandra et al., 2011). Phospolipids called commercial soy lecithin also typically contain roughly

phosphatidylcholine at 33.0%, 16.8% of phosphatidylinositols and 0.4% of phosphatidylserine respectively (Alejandra et al., 2011). In the end, lecithin contains a lot of complexed and versatile substances extracted from the soybean (Jones et al., 1990a).

The term "lecithin" is originated from the Greece word *lekithos* meaning "egg yolk." (Wendel et al., 2000). In 1846 Gobley isolated lecithin from egg yolk and in 1850 gave it its present name (Maclean and Maclean 1927). They began to call it “lecithine” by the late 1800s. Nowadays, in English, the word "lecithin" has two different meanings in which one of them means naturally blended complex of phosphatides to food industries people and the chemically pure phosphatide, phosphatidyl choline (Xing et al., 2004). The general word "soybean phosphatides" may be called to express the oil-free lecithin complex (http://www.soyinfocenter.com/HSS/lecithin1.php).

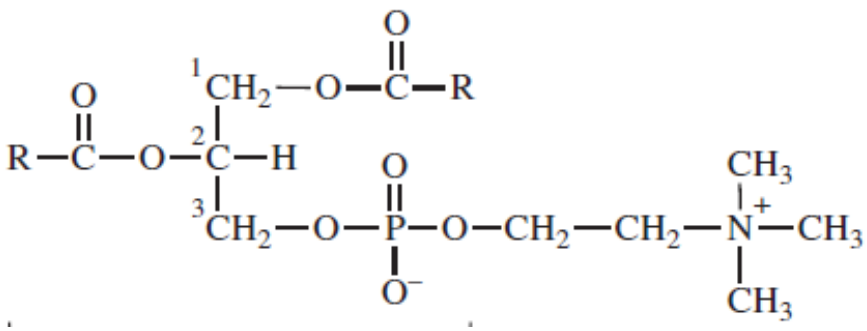

Figure7. Chemical structure of lecithin (Alejandra et al., 2011)

In young piglets, it plays a role as an emulsifier with improving fat digestibility (Frobish, 1969; Jones et al., 1990a, 1992). Weaning piglets just seperated from their sows undergo abrupt feed shifts from soft and liquid sow milk to hard and solid piglet feeds, which affect growth retaradation and underfeeding just after weaning (Dividich et al., 1980; Seve, 1982). Therefore, we have to try to find solution before they get any negative impact from weaning. For it, increasing enery value in piglet diets could be one of the atenatives thus supplementing fats in piglet diets are recommended (Corring et al., 1978; Lindemann et al., 1986). However, after weaning the activity of pancreatic lipase in piglets begins to decrease so we have to try to find how to increase fat digestibility (Jones et al., 1992)

Lecithin could be one of important factors which can increase lipid digestibility (Xing et al., 2004). Schwarzer and Adams (1966) reported that weight gain and FCR might be improved by lecithin in the piglet until body weight 22kg. Lecithin showed better effects on piglet performance just after weaning (Soares et al., 2002). And also Gu and Li (2003) observed that when they used lecithin in the weaning piglet feeds, it's more effective than others. Even though the lecithin was applied to increase lipid digestion and utilization in animal feeds, lecithin supplementation showed also better digestibility of other nutrients (Xing et al., 2004).

There were a few experiments which showed better performance on ADG and FCR with lecithin (Rodas et al., 1995; Heughten and Odle, 2000; Xing et al., 2004; Danek et al., 2005; Smulders, 2008). In contrast, according to Overland et al. (1993a), lecithin from soy did not show any fat digetibility difference in the weaning pigs. A few studies were reported that the fat digetibility of piglets showed the difference between fats from animal and fats from plant, that is to say, plant origin fats are more digestible that animal fats (Cera et al., 1988a; 1989; Li et al., 1990; Jones et al., 1992). Therefore, when we formulate piglet feeds with lecithin sumpplementation, we have to consider the fat digestibility with various lipid sources through other experimental results.

4. Lysophospolipids in swine diets

4.1 Definition and information of lysophospolipids

Lysophospholipid are glycerophospholipids where one acyl chain is deficient and only one hydroxyl group from the glycerol backbone is acylated (Paola et al., 2010). An enzymatic diversion of lecithin generates LPL (Matias, 2015). One of the fatty acids in the phospholipids is removed by the phospholipase during the enzymatic conversion and with this way phospholipids are turned into lysophospholipids (Joshi et al., 2006). Phospholipids and lysophospholipids all have

hydrophilic head groups and hydrophobic tails giving them surface active (Matias et al., 2015).

According to Zhang et al. (2011), it was asserted that lecithin and lysolecithin both work as an emulsifier in the beginning of fat digestion and enhance the active area of fat droplets. However, lysophospholipids become more hydrophilic than phospholipids and have better Oil/Water emulsifying agents than phospholipids by the elimiantion of one fatty acid (Joshi et al., 2006; Liu and Ma, 2011). Furthermore, when phospholipids and lysophospholipids proceed at the surface of emulsified fat droplets and in the water soluble condition of the intestine, all two agents may act reciprocally with the fat hydrolysis procedure (Dahim and Brockman, 1998; Reis et al., 2009; Reis et al., 2010). And the liquidity and penetrability of membraines can be improved by lysophospholipids (Lundbaek and Andersen, 1994; Wendel, 2000; Lundbaek, 2006). As a result, more nutrition absorption could be occurred in the membrane of the villi of small intestine by this lysophosphplipids (Lundbaek and Andersen, 1994).

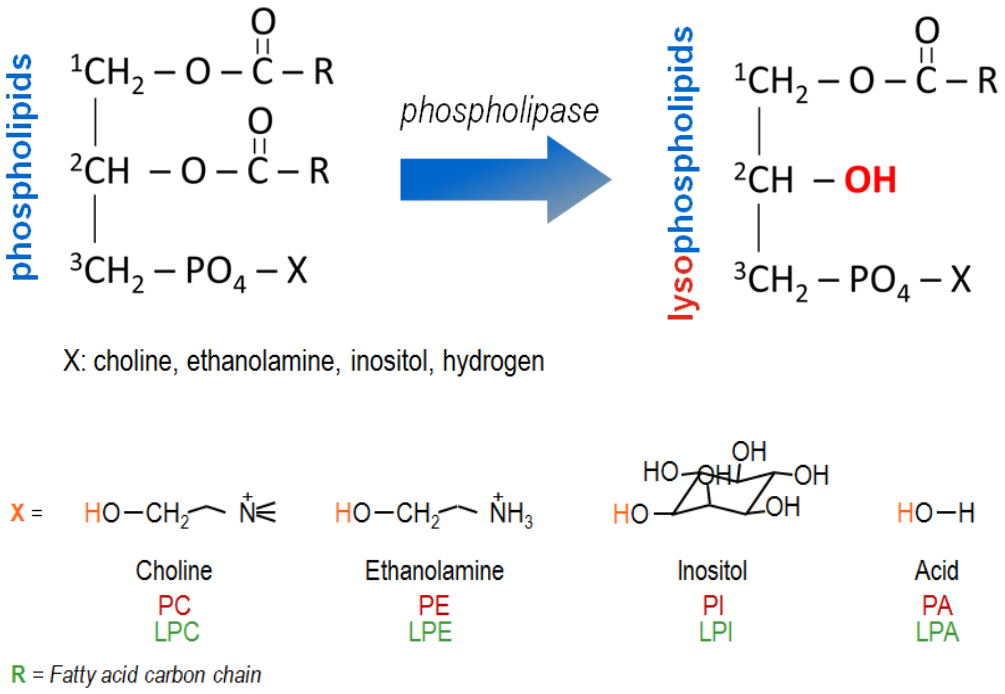

Figure 8. Enzymatic conversion of phospholipids into lysophospholipids (kemin Ind.)

Aoi (1990) observed that dietary protein and soy-lysolecithin have close interaction which may affect protein digestibility and absorption. Very small micelles are formed by lysolecithin naturally that has critical micelle concentration (CMC) of 0.02–0.2 mM/L and it is 20–200 times better than natural bile acid (CMC = 4 mM/L) and general lecithin (CMC = 0.3–2 mM/L) (Zubay, 1983; Langmuir, 2002). It is indicated that lysolecithin has better emulsifying ability and the capacity of micelle forming than natural bile salts and any other emulsifiers, showing itself an excellent source as an exogenous emulsifier (Zhanga et al., 2010).

► **Hydrophilic-lipophilic balance (HLB)**

The hydrophilic-lipophilic balance is one of the methods to express the degree whether it is hydrophilic or lipophilic and calculated values for the different areas of the molecule become the HLB degree, which was devised by Griffin in 1949 and 1954 (Wikipedia, 2016). Davies also developed other method to measure HLB in 1957 (Wikipedia, 2016).

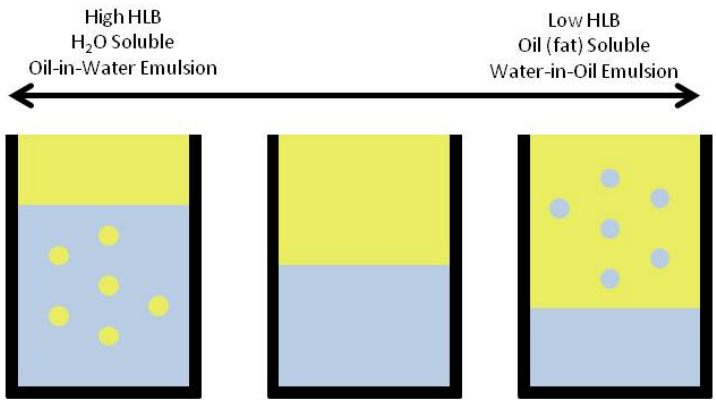

Figure 9. Definition of hydrophilic-lipophilic balance (HLB)

- **Griffin's method**

Griffin's method for non-ionic surfactants as described in 1954 works as follows:

$$HLB = 20 * M_h/M$$

here M_h means the molecular compound of the hydrophilic part, and M refers to the molecular mixture of the entire molecule, which is marked 0 to 20 (Wikipedia, 05/06/2016).

- **Davies' method**

New method to measure HLB values was introduced by Davies in 1957, which is in the basis of values related with chemical groups of the molecule (Wikipedia, 05/06/2016). The best merit of this method is that we can consier even the effect of strong and weak hydrophilic groups (Wikipedia, 05/06/2016). His uinique calculation method as follows:

$$HLB = 7 + \sum_{i=1}^{m} H_i - n \times 0.475$$

m- Number of hydrophilic groups in the molecule

Hi - Value of the i^{th} hydrophilic groups

n- Number of lipophilic groups in the molecule

HLB (Hydrophile-Lipophile Balance) values mean the surfactant corelationship between the hydrophilic ("water-loving") groups and hydrophobic ("water-hating") groups so the lower the HLB value, the less water-soluble the surfactant (Verma et al., 2009).

4.2 The main role of lysophospholipids on lipid digestion and absorption

Lipid digestion and absorption may be improved by the activity of bile salts which emulsify fats to form smaller micelles for easier aborption in small intestine (Gomez et al., 1976). However, the production amount of bile salts is not enough from birth to early growing stage in swine (Kitts et al., 1956). Many researchers and studies have shown that lower emulsification rather than the insufficiency of lipase activity causes poor fat digestion at early stages in swine (Hartman et al., 1961; Gomez et al., 1976), therefore LPL application has been interested considerably in swine industry as a mean of increasing the utilization of lipids in young pigs (Zhanga et al., 2010).

Lysophospholipid is recognized as an important componet in pig nutrition because it is one of excellent biosurfactants (Zhanga et al., 2010). The combiantion of lipophilic and hydrophilic with mixture of lysophospholipids induce them to act as biosurfactant when they are mixed with water and oil (Jones et al., 1990b). So, supplementing lysophospholipids in the swine diets has shown improving the fat digestibility and absorption in weaning piglets through increasing the fat emulsification (Superchi et al., 1996).

Lysophospholipids made by the hydrolysis of lecithin are more hydrophilic than phospholipids since one fatty acid remains per molecule in lysophospholipids (Joshi et al., 2006; Liu and Ma, 2011). Consquently, lysophospholipids get better emulsification by the converted lecithin and also are able to form spherical micelles in an aqueous environment to solubilize water-insoluble substances in translucent state unlike lecithin (Kemin industries). This characteristic is changed to increase the emulsification effect that lets it better emulsifier for application in ‘O/W’ emulsions like occuring in GI tract (Kemin industries).

Also there is the excellent ability of forming micelles with fatty acids, monoglycerides and bile salts in phospholipids (Zhang et al., 2011). Compared with other common phosphatidylcholine, lysophosphatidylcholine containing with linoleic acid has shown remarkably small and more stabilized ovalbumin emulsions

in forming micelles (Zubay, 1983; Langmuir, 2002). Actually, there is a possible hypothesis that the blended micelles would not be normal and the fat absorption, expecially free fatty acids would be seriousely decreased if lecithin was not hydrolyzed (Saunders et al., 1976). To veryfy this assumption, they put micellar solutions of linoleic acid to the isolated small part of the rat intestine *in vivo* and also inserted taurocholate to there with 1-palmitoyl lysolecithin, 1-palmitoyl, 2-oleoyl lecithin which are the hydrolytic product of lecithin (Saunders et al., 1976). As a result, free fatty acid aborption rate was decreased almost by 40% in small intestine where generally the absorption of free fatty acid occurs with lysolecithin (Saunders et al., 1976). This experiment indicates that lysolecithin acts as an important role in fat digestion process.

A few researchers have reported that fat digestion begins with bile salts lysophospholipids together in the first step of whole processes so their fat digestion and absorption is improved more by the lysophospholipids which involve in immune system existing in the swine. (Hartman et al., 1961; Gomez et al., 1976) Lysophospolipids become more hydrophilic and work better in O/W emulsifying situation than phospholipids since one fatty acid is removed (Joshi et al., 2006; Liu and Ma, 2011).

The lysophospholipids in lysolecithin play an important role in improving fat digestibility as emulsifier (Zhang et al., 2011). Bigger fat droplets are changed

into smaller fat droplets to make lipase act easier by LPL activity on fats, therefore, lipase acitivity also could be increased by more emulsification, increasing the total workable surfaces and causing to an increased fat hydrolysis with lysophospholipids (Dahim and Brockman, 1988; Reis et al., 2008a). However, the chemically different constitutions and concentrations of active mixtures in the surface area including phospholipids and lysophospholipids may affect the lipase activity and fat absorption (Dahim and Brockman, 1988; Reis et al., 2008a; Reis et al., 2008b; Mandalari et al., 2009; Reis et al., 2010; Malaki et al., 2011; Maldonado-Valderrama et al., 2011; Verrijsen, 2015).

Lysophopholipids also induce to enhance lipid hydrolysis in the fat digestion process and thus, lysophospholipids form smaller mixed micelles which make thsese monoglycerides and free fatty acids combined together (Matias, 2015). Therefore, lysophospholipids act critically in reorganizing monoglycerides and free fatty acids from the surfaces, making fat hydrolysis keep going with this interference regarding mixed micelles formation (Matias, 2015).

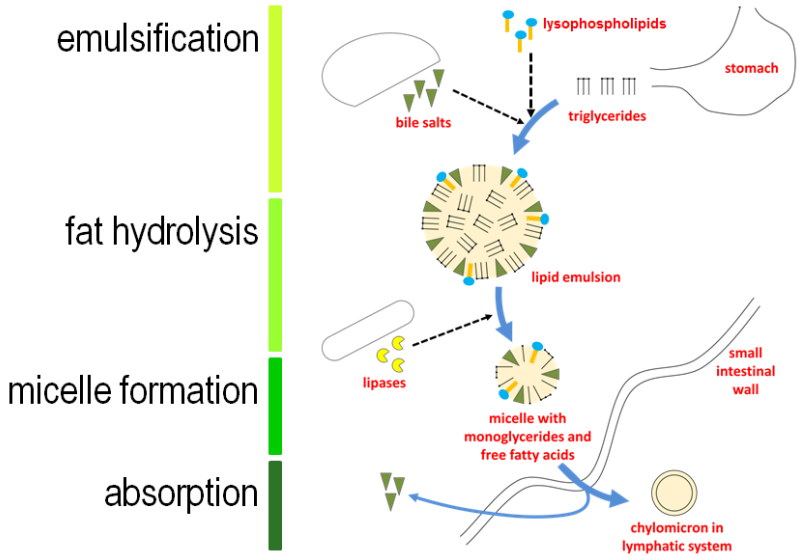

Figure 10. The role of lysophospholipids on lipid digestion (Kemin Ind.)

4.3 Effects of exogenous lysophospholipids on swine performance and lipid digestiblity in swine diets

A few researchers reported that exogenous lysophospolipids showed positive effects on lipid digestion in swine (Papadopoulos et al., 2014; Xing et al., 2004). Xing et al. (2004) reported that lysophospolipids showed better performance with average daily gain (ADG) during 15–35 days after weaning and all periods, however, did not show any difference in average daily feed intake (ADFI) and feed conversion ratio (FCR). Overland and Sundstol (1995) also observed that FCR

during 0–14 days after weaning was improved by phospholipids supplementation and ADG also increased during the whole period. Recently, there was also another LPL supplementation trial in swine and according to the report, the lysophospholipids supplementation in swine diet showed increased ADG in weaning pigs fed with reduced energy (10.32 MJ/kg) diet and supplementation of LPL also improved the ATTD of DM, GE, N and CP, however decreased triglyceride concentration in serum of weaning pigs (Zhao et al., 2015). In particular, 0.1% LPL treatment showed better performance in every measurement, but 0.05% LPL treatment didn't show better performance compared with control group in this experiment (Zhao et al., 2015).

Jones et al. (1995) also reported that the increment of 4% fat digestibility in tallow was observed with lysolecithin supplement. However, supplementing lysolecithin didn't show improved disgestibility in coconut oil because the coconut oil contains a lot of short and medium chain fatty acids which is aleady highly digestible in digestion and absorption mechanisms (Jones et al., 1995).

In other research, treatment group with lysolecithin showed better FCR (feed coversion ratio) in their trial experiment (from weaning to 40 days). However, except FCR, any significant differences were not shown in the experiment (Papadopoulos et al., 2014). Xing et al. (2004) also reported that nutrient digestibility appeared to be no close relationship with the improvement of pig

performance, in which actual digestibility was decreased with lysolecithin supplementation. In addition, Overland et al. (1994) did not suggest any benefits in weaning phase or in grower-finisher phases regarding growth performance and fat digestibility with using soy lecithin as an emulsifier.

Therefore, the objectives of this research are to demonstrate the effects of LPL supplementation on growth performance, nutrients digestibility and energy sparing in growing pigs and on sows' performance.

III. Energy sparing effects of dietary LPL in weaning and growing pigs

Abstract: This study was conducted to evaluate energy sparing effect of lysophospholipid (LPL) on growth performance and productivity from weaning to growing pigs. A total of 140 crossbred ([Yorkshire × Landrace] × Duroc) pigs with averaging 7.3 ± 1.62 kg of initial body weight were randomly allotted to one of four treatments based on sex and initial body weight according to randomized complete block (RCB) design in 5 replicates with 7 pigs per pen. The 2 × 2 factorial arrangements were used and the first factor was dietary energy levels (3,200 or 3,300 kcal ME/kg), and the second factor was supplementation of LPL (Supplementation levels: 0 or 0.05%). Experimental pigs were fed corn-barley-soybean meal based diets and feeding program is composed of three phases (Phase I, 0-2 week; Phase II, 3-5 week; Phase III, 6-10 week). In Phase I, improvements of average daily gain (ADG) and average daily feed intake (ADFI) were not affected by dietary treatments. However, gain to feed (G/F) ratio was increased in low energy treatment (P=0.04) and tended to be higher when LPL was supplemented. In phase II (3-5 week), both dietary energy level and LPL supplementation had no effect on growth performance. In Phase III, increased ADG (P<0.01) and tendency of improving G/F ratio (P=0.09) were observed when LPL was added to diets. Supplementation of LPL improved ADG by 15% and 11% in 6-10 week and 0-10

week, respectively. Also, supplementation of LPL improved G/F ratio by 20% in 6-10 week and 13 % in 0-10 week. The feed cost/weight gain was reduced when pigs were fed diets containing LPL during all the experimental periods except for Phase II. Consequently, this experiment demonstrated that LPL supplementation to growing pigs' diet can improve growth performance and productivity with reducing production cost of pigs.

Key words: Lysophospholipid, Energy level, Growth performance, Economics, Pig

INTRODUCTION

International prices of major feed ingredients such as corn, soybean meal and wheat have been increased since 2006 because bio-fuel production with grains was increased (Moon, 2012). It caused a higher feed cost for animal production and also influenced on total production cost in swine farm because feed cost is composed of approximately 60 ~ 70% of total swine production cost (Wilson and Bayer, 2000). Especially, raw materials such as oils as energy sources have higher prices than other raw materials (Saleh et al., 2004). Therefore, decreasing energy level in pig diets or using cheaper feed ingredient could be an important issue in total production cost saving as well as feed cost saving in swine industry.

Supplementation of exogenous emulsifer in swine diet has taken a great attention as an alternative feed additive for reducing feed cost (Moon, 2012). LPL is a substance that stabilizes fat emulsion by increased kinetic stability and helps the fat digestion in animal body (Davis, 1990). This effect of LPL enhances the fat availability (Papadopoulos et al., 2014; Xing et al., 2004) therefore we can reduce the feed cost by decreasing energy in the swine diets. So, many researchers have evaluated the effects of exogenous emulsifiers such as lecithin and lysolecithin in swine diet. In some studies, dietary lecithin increased the apparent digestibility of

total dietary fat in human diets (Aldersberg and Sobotka, 1943), calves (Havrevoll, 1984) and chicks (Polin, 1980).

Weaning pigs have a low secretion of bile acid for fat digestion, resulting in lower utilization of dietary fat (Frobish et al., 1970; Cera et al., 1989). Thus, they showed positive results on growth performance in weaning pigs with LPL supplementation which improved fat digestibility (Cera et al., 1990; Howard et al., 1990; Li et al., 1990). According to Overland et al. (1995), LPL supplementation in swine diets increased the action of bile acid in gastrointestinal tract, influencing on improvement of fat digestibility, and subsequent growth performance in weaning pigs.

Consequently, the aim of this study was to investigate effects of dietary LPL supplementation on growth performance and economical benefits in weaning and growing pigs.

MATERIALS AND METHODS

Experimental design and diet

A total of 140 crossbred ([Yorkshire × Landrace] × Duroc) pigs with averaging 7.3 ± 1.62 kg of initial body weight were randomly assigned to each treatment based on sex and initial body weight according to randomized complete

block (RCB) design in 5 replicates with 7 pigs per pen. The 2 × 2 factorial arrangements were used and the first factor was dietary energy level (3,200 or 3,300 kcal of ME/kg) and the second factor was supplementation of lysophospholipids(LPL 0% or 0.05%). Major ingredients for experimental diets were corn, barley and soybean meal and three phase feeding programs were used in this experiment. Diets for Phase I (0 to 2 week), II (3 to 5 week) and III (6 to 10 week) contained 23.7%, 20.9% and 18.0% crude protein and 1.35%, 1.15% and 0.95% total lysine, respectively. The experimental diets were provided by a local feed company and LPL (lysolecithin content 25% from Kemin Industries (Asia) Pte Ltd, Singapore) was supplemented to 2 each treatment (L2 and H2). All nutrients of experimental diets were met or exceeded the nutrient requirement of NRC (2012), and formula and chemical composition of experimental diets were presented in Tables 1, 2 and 3.

Animal management and measurement

Pigs were housed in whole slatted 1.5 × 2.0m plastic floor equipping a feeder and a nipple drinker to allow freely access to feed and water during the overall experiment period. The ambient temperature was kept at 31 ℃ during the first 7 days and lowered 1 ℃ every week. Body weight (BW) and feed consumption were recorded at 0, 2, 5 and 10 week to calculate average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G/F ratio).

Economic analysis

Economic analysis was conducted to compare the feed cost for 1 kg weight gain. Calculation of feed cost per weight gain is as following.

Feed cost / weight gain (won/kg) =

Feed price(won/kg) × Feed intake per head(kg/pig)/ Weight gain per head(kg/pig)

The feed cost per weight gain was calculated based on price of raw materials at the time of the experiment (September, 2013).

Blood sampling

Blood samples were taken from anterior vena cava of 5 pigs per treatment for measuring BUN (blood urea nitrogen), triglycerides, total cholesterol, HDL (High density lipoprotein) and LDL (Low density lipoprotein) when each period was finished. The collected blood samples were centrifuged for 15 min at 3,000 rpm on 4 ℃ (Eppendorf centrifuge 5810R, Germany). The sera were carefully transferred to 1.5 ml plastic tubes and stored at –20 ℃ until analysis. To evaluate the efficiency of protein utilization in the body, total BUN concentration was analyzed using a blood analyzer.

Chemical and statistical analysis

All data were analyzed as a completely randomized design with a 2 × 2 factorial arrangement of treatments by using the General Linear Model (GLM) procedure of SAS (SAS Institute, 2004). Probability values less than 0.05 ($P<0.05$) were considered as significant difference; $0.05<P<0.10$ were indicative about some trend; and values equal to or greater than 0.10 were considered as nonsignificant difference.

RESULTS AND DISCUSSION

Growth performance

The effect of dietary energy level and supplementation of LPL on growth performance was presented in Table 4. There were no differences in body weight (BW) at 2 week and 5 week. However, pigs fed diets containing LPL had higher body weight than those fed diets without LPL at 10 week ($P=0.04$). Although there were no effects of dietary treatment on ADG at 0-2week, 3-5week, and 0-5 week, ADG at 6-10 week and 0-10 week was improved significantly when LPL was supplemented to diets ($P<0.01$). In 6-10 week and 0-10 week, supplementation of LPL resulted in improving ADG by 15% and 11%, respectively (Figure 1). Also pigs fed high energy diet showed numerically higher ADG than those fed low energy diet

(*P*=0.09). Dietary energy level and supplementation of LPL had no effect on average daily feed intake during the overall experiment period, but G/F ratio was improved when pigs were fed diets containing low energy at 0-2 week (*P*=0.04), 0-5 week (*P*=0.07) and LPL supplementation at 6-10 week (*P*=0.04), 0-10 week (*P*=0.04) respectively (Figure 2).

Increased ADG by dietary energy level in the present study is agreed with De la Llata et al. (2001) and Young et al. (2003). De la Llata et al. (2001) demonstrated that adding 6% fat to diet with increasing energy density improved ADG in growing pigs and Young et al. (2003) also observed that adding 2.5% and 5% fat to the diet of growing pig results in a 2% and 2.1% improvement in ADG, respectively. Present study also demonstrated that growth performance of growing pig was improved approximately 4.1% of ADG in overall experimental period when fed high energy diets (H1 and H2) compared with low energy diets (L1 and L2).

In spite of difference in dietary energy level, there was no significant difference in ADFI during the overall experimental period. The result of ADFI was in consistent of the observations of Zhang et al. (1984), Matthews et al. (1998) and Urynek and Buraczewska (2003). However, some researchers have shown that increasing energy density in swine diets induced a decrease of ADFI (De la Llata et al., 2001; Matthews et al., 2003). De la Llata et al. (2001) reported that increasing

energy level ranged from 3.31 to 3.65 Mcal/kg increased ADG and decreased ADFI. These controversial results were caused by difference of energy density in diets.

Supplementation of LPL had no effect in ADFI during overall period. Although some research demonstrated that LPL had a positive effect on feed intake (Zhao et al., 2015), this current study had no effect of LPL on ADFI in accordance with Jones et al. (1992), Overland et al. (1993, 1994), Rodas et al. (1995) and Xing et al. (2004). Considering the previous studies, LPL did not influence on feed intake or control voluntary feed intake of growing pigs although supplementation of LPL improved the nutrient digestibility and growth performance.

The result of improved G/F ratio was in agreement with the finding of Overland et al. (1993) which conducted the experiment (two levels of lecithin (0 and 2%) at two levels of soy oil (0 and 6%)) to evaluate the effect of lecithin in weaning pigs. However, the supplementation effect of LPL in this current experiment was not observed in weaning pigs' period but growing pigs' period. Young pigs have low capacity of fat utilization and their digestibility of fat is improved as they grow up (Cera et al., 1990). As the limitation of lipase secretion (Hardy, 1990), emulsified micelles were not fully digested in period of weaning pig. On the other hand, growing pigs have a higher activity of the lipolytic enzymes produced by the pancreas than that of piglets (Bontempo et al., 1994; Bee et al., 1996), nevertheless

significant effect of LPL was observed in growing pigs rather than in weaning pigs in current study.

Some researches demonstrated that LPL supplementation improved fat digestibility (Jones et al., 1992; Superchi et al., 1996; Jin et al., 1998) or digestibility of dry matter, organic matter and crude protein (Jones et al., 1992; Dierick and Decuypere, 2004). However, Xing et al. (2004) observed that nutrient digestibility seemed to have no close relationship with the improvement of pig performance, in which actual digestibility was decreased with lysolecithin supplementation. In addition, Overland et al. (1994) did not show any benefits in weaning phase or in grower-finisher phases regarding growth performance and fat digestibility with using soy lecithin as an emulsifier. Considering previous studies, the results of current study could be explained that improvement of growth performance in growing period by LPL supplementation was related with increasing amount of lipase secretion as the pigs grew older (6-10 week).

Economic analysis

The feed cost/weight gain was decreased numerically when pigs were fed L2 (low energy diet supplemented LPL) at Phase I (Table 6). However, there were no effects on feed cost/weight gain in H2 (higher energy diet with LPL) compared with other 3 treatments in Phase II, resulting in the highest feed cost/weight gain of pig

among them. However, LPL supplementation improved growth performance regardless of dietary energy levels, resulting in 20% (L2) and 10% (H2) decrease in the feed cost/pig weight gain respectively compared with L1 in Phase III.

Except for phase I, supplementation of LPL had a positive effect on feed cost/weight gain in all phases. In phase II, a positive effect of LPL supplementation was observed in the pigs fed diets with lower energy (3,200 kcal of ME/kg). Interestingly, G/F ratio was improved a lot about 10~20% by supplementation of LPL regardless of dietary energy levels. Especially in growing period (6-10 week), L2 (lower energy diet with LPL) resulted in a decrease approximately 20 % of feed cost/weight gain compared with L1 (lower energy diet - 3,200 kcal ME/kg).

Blood metabolites

The effect of dietary LPL in weaning and growing pigs on blood metabolites was presented in Table 5. There was no significant difference in tri-glycerides level. However, L2 (3,200kcal + LPL) tended to increase tri-glycerides level at 5 week (P=0.07). There were also significant differences in LDL, HDL and HDL : LDL ratio. LDL level showed significant difference at 2 week (P=0.02) and 5 week (P=0.02 in energy and P=0.01 in LPL, respectively) and also there was significant difference in HDL level in energy at 5 week (P=0.03). HDL : LDL ratio in energy showed also significant difference at 5 week (P=0.03). Blood BUN

concentration at 5 week (*P*=0.01 in energy and *P*=0.05 in LPL, respectively) and 10 week (*P*=0.01 in energy) showed significant differences.

Roy et al. (2010) reported that there were no significant differences in HDL when they supplemented emulsifier in broiler. However, there was difference that LDL level decreased as the amount of emulsifier increased in the diets. And also HDL : LDL ratio increased as emulsifiers in the diets increased in their experiments. According to Jones et al. (1992), LDL cholesterol might decrease when lecithin was fed as an emulsifier in pigs. The results of their experiments agreed with current study that LDL cholesterol level in pigs fed LPL was lower compared with pigs fed diets without LPL supplementation. However, LDL, HDL or triglyceride levels were not influenced by dietary lipid sources or emulsifier supplementation (Neto et al., 2011). In this current study, differences were observed on LDL, HDL and LDL : HDL cholesterol with LPL supplementation. Even though these results can't be explained clearly regarding mode of acitons, obviousely LPL may influence on their better health conditions. In BUN, although there were differences in BUN at 5 week according to energy and LPL supplementation (*P*=0.01 and *P*=0.01, respectively) and 10 week (*P*=0.01) in energy, they did not affect growth performance negatively.

CONCLUSION

When experimental pigs were fed diets (L2, H2) containing LPL, significant improvement was shown on body weight gain, ADG and G/F ratio in this study. Especially, when pigs were fed L2 (3,200 kcal of ME/kg with LPL), growth performance was much better than that of H1 (3,300 kcal of ME/kg without LPL). Moreover, feed cost was saved approximately 20% by L2 (3,200 kcal of ME/kg with LPL) compared with L1 (3,200 kcal of ME/kg without LPL). On the other hand, there was no detrimental effect on growth performance in phase I, II although spectacular growth performance was presented in phase III. Dietary LPL supplementation did not affect ADFI during overall experiment period.

In summary, current study showed that supplementation of LPL improved body weight gain, ADG and G/F ratio especially in growing pigs (phase III) rather than in weaning pigs (phase I, II) and also contributed feed cost saving with increased efficiency and reduced energy 100 kcal of ME/kg in swine diets without negative effect on ADFI, decreasing total swine production cost in economical efficiency.

Table 1. Ingredients and chemical compositions of experimental diet in 0-2 week

	Treatments[1]			
Ingredients, %	L1	L2	H1	H2
EP[5] Corn	3.37	3.96	15.49	15.99
SBM[6]-44	39.36	39.45	41.37	41.44
Whey powder	3.00	3.00	3.00	3.00
Lactose	8.00	8.00	8.00	8.00
Barley	36.37	35.63	22.68	22.06
Sugar beet pulp	6.18	6.18	4.66	4.66
Tallow	1.00	1.00	2.00	2.00
MCP[7]	0.98	0.99	1.02	1.02
Limestone	0.85	0.85	0.91	0.91
L-Lysine·HCl	0.17	0.17	0.16	0.16
DL-Methionine	0.03	0.03	0.03	0.03
Threonine	0.05	0.05	0.04	0.04
Vit. Mix[2]	0.12	0.12	0.12	0.12
Min. Mix[3]	0.12	0.12	0.12	0.12
Salt	0.20	0.20	0.20	0.20
Choline·Cl[8](25%)	0.10	0.10	0.10	0.10
ZnO	0.10	0.10	0.10	0.10
LPL(Lysophospholipids)	0.00	0.05	0.00	0.05
Total	100.00	100.00	100.00	100.00
Chemical composition[4]				
ME, kcal/kg	3,200.00	3,200.00	3,300.00	3,300.00
CP[9], %	23.70	23.70	23.70	23.70
Total lysine, %	1.35	1.35	1.35	1.35
Total methionine, %	0.35	0.35	0.35	0.35
Total threonine, %	0.86	0.86	0.86	0.86
Ca, %	0.80	0.80	0.80	0.80
Total P, %	0.65	0.65	0.65	0.65

[1] Treatment L1(3,200 kcal of ME/kg + 0 % LPL), Treatment L2(3,200 kcal of ME/kg + 0.05 %LPL), Treatment H1(3,300 kcal of ME/kg + 0 % LPL), Treatment H2(3,300 kcal of ME /kg + 0.05 % LPL). Lysolecithin content 25% from Kemin Industries.

[2] Vitamin Mix. Provided the following quantities of vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin $D_{3,}$ 1600 IU; vitamin E, 32 IU; D-biotin, 64g; riboflavin, 3.2mg; calcium pantothenic acid, 8 mg; niacin, 16mg; vitamin $B_{12,}$ 12g; vitamin K, 2.4 mg

[3] Mineral Mix.Provided the followings quantities of mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu-SO_4, 54.1mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4] Calculated values

[5] EP : Expanding

[6] SBM : Soybean meal

[7] MCP : Mono calcium phosphate

[8] Cl : Chloride

[9] CP : Crude protein

Table 2. Ingredients and chemical compositions of experimental diet in 3-5 week

	Treatments[1]			
Ingredients,%	L1	L2	H1	H2
EP[5] Corn	16.73	17.23	27.50	28.00
SBM[6]-44	31.34	31.42	33.11	33.18
Whey powder	0.00	0.00	0.00	0.00
Lactose	4.00	4.00	4.00	4.00
Barley	39.15	38.52	27.78	27.16
Sugar beet pulp	5.51	5.51	3.30	3.30
Tallow	1.00	1.00	2.00	2.00
MCP[7]	0.91	0.90	0.92	0.92
Limestone	0.62	0.63	0.68	0.68
L-Lysine·HCl	0.16	0.16	0.15	0.15
DL-Methionine	0.01	0.01	0.00	0.00
Threonine	0.03	0.03	0.02	0.02
Vit. Mix[2]	0.12	0.12	0.12	0.12
Min. Mix[3]	0.12	0.12	0.12	0.12
Salt	0.20	0.20	0.20	0.20
Choline·Cl[8](25%)	0.10	0.10	0.10	0.10
ZnO	0.00	0.00	0.00	0.00
LPL(Lysophospholipids)	0.00	0.05	0.00	0.05
Total	100.00	100.00	100.00	100.00
Chemical composition[4]				
ME, kcal/kg	3,200.00	3,200.00	3,300.00	3,300.00
CP[9], %	20.90	20.90	20.90	20.90
Total lysine, %	1.15	1.15	1.15	1.15
Total methionine, %	0.30	0.30	0.30	0.30
Total threonine, %	0.74	0.74	0.74	0.74
Ca, %	0.70	0.70	0.70	0.70
Total P, %	0.60	0.60	0.60	0.60

[1] Treatment L1(3,200 kcal of ME/kg + 0 % LPL), Treatment L2(3,200 kcal of ME/kg + 0.05 %LPL), Treatment H1(3,300 kcal of ME/kg + 0 % LPL), Treatment H2(3,300 kcal of ME /kg + 0.05 % LPL). Lysolecithin content 25% from Kemin Industries.

[2] Provided the following quantities of vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin $D_{3,}$ 1600 IU; vitamin E, 32 IU; D-biotin, 64g; riboflavin, 3.2mg; calcium pantothenic acid, 8 mg; niacin, 16mg; vitamin $B_{12,}$ 12g; vitamin K, 2.4 mg

[3] Provided the followings quantities of mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu-SO_4, 54.1mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4] Calculated values

[5] EP : Expanding

[6] SBM : Soybean meal

[7] MCP : Mono calcium phosphate

[8] Cl : Chloride

[9] CP : Crude protein

Table 3. Ingredients and chemical compositions of experimental diet in 6-10 week

	Treatments[1]			
Ingredients,%	L1	L2	H1	H2
Corn	40.91	41.47	53.70	54.25
SBM[5]-44	23.71	23.79	26.02	26.11
Barley	26.77	26.08	12.00	11.31
Wheat bran	5.55	5.55	4.07	4.07
Tallow	1.00	1.00	2.00	2.00
MCP[6]	0.62	0.62	0.68	0.68
Limestone	0.80	0.80	0.91	0.91
L-Lysine·HCl	0.14	0.14	0.12	0.12
DL-Methionine	0.00	0.00	0.00	0.00
Threonine	0.00	0.00	0.00	0.00
Vit. Mix[2]	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
LPL(Lysophospholipids)	0.00	0.05	0.00	0.05
Total	100.00	100.00	100.00	100.00
Chemical composition[4]				
ME, kcal/kg	3,200.00	3,200.00	3,300.00	3,300.00
CP[7], %	18.0	18.0	18.0	18.0
Total lysine, %	0.95	0.95	0.95	0.95
Total methionine, %	0.25	0.25	0.25	0.25
Total threonine, %	0.61	0.61	0.61	0.61
Ca, %	0.60	0.60	0.60	0.60
Total P, %	0.50	0.50	0.50	0.50

[1] Treatment L1(3,200 kcal of ME/kg + 0 % LPL), Treatment L2(3,200 kcal of ME/kg + 0.05 %LPL), Treatment H1(3,300 kcal of ME/kg + 0 % LPL), Treatment H2(3,300 kcal of ME /kg + 0.05 % LPL). Lysolecithin content 25% from Kemin Industries.

[2] Provided the following quantities of vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1600 IU; vitamin E, 32 IU; D-biotin, 64g; riboflavin, 3.2mg; calcium pantothenic acid, 8 mg; niacin, 16mg; vitamin B_{12}, 12g; vitamin K, 2.4 mg

[3] Provided the following quantities of mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu-SO_4,

54.1mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4] Calculated values

[5] SBM : Soybean meal

[6] MCP : Mono calcium phosphate

[7] CP : Crude protein

Table 4. The effect of dietary energy levels and supplemental LPL on growth performance of pigs[1]

Item	Treatments				SEM[2]	P-value		
	L1	L2	H1	H2		Energy	LPL	E X L
Body weight[3], kg								
Initial	7.27	7.31	7.30	7.32	0.35			
2 week	11.16	11.09	10.83	10.83	0.49	0.79	0.97	0.98
5 week	18.79	19.12	18.75	19.18	0.74	0.99	0.82	0.97
10 week	37.40	40.58	38.59	42.04	0.81	0.40	0.04	0.93
Average daily gain, g								
0-2 week	277.8	270.4	252.4	251.1	11.51	0.37	0.86	0.90
3-5 week	363.5	382.0	376.9	397.5	13.93	0.63	0.52	0.97
5-10 week	531.7	613.3	567.0	653.3	14.36	0.09	0.01	0.91
0-5 week	329.2	337.4	327.1	338.9	11.85	0.99	0.70	0.94
0-10 week	430.5	475.3	447.0	496.1	8.56	0.19	0.01	0.88
Average daily feed intake, g								
0-2 week	474.9	458.4	504.9	475.5	20.16	0.59	0.60	0.88
3-5 week	657.8	615.2	662.7	726.7	30.39	0.37	0.87	0.41
5-10 week	877.4	804.2	950.8	948.7	34.20	0.13	0.59	0.61
0-5 week	584.6	552.5	599.6	626.2	24.31	0.40	0.96	0.57
0-10 week	731.1	678.4	775.2	787.4	25.79	0.16	0.71	0.54
G/F ratio								
0-2 week	0.587	0.593	0.508	0.531	0.0166	0.04	0.65	0.80
3-5 week	0.574	0.617	0.577	0.549	0.0161	0.34	0.82	0.30
5-10 week	0.616	0.775	0.619	0.702	0.0297	0.54	0.04	0.51
0-5 week	0.572	0.610	0.549	0.544	0.0120	0.07	0.49	0.36
0-10 week	0.601	0.706	0.587	0.637	0.0192	0.25	0.04	0.44

[1]Total of 140 crossbred pigs was fed diets from averaged initial body weight 7.29kg.

[2]Standard error of the mean.

[3]Values are means for each pen of seven pigs.

Table 5. The effect of dietary energy levels and LPL supplementation on blood profiles of pigs.

Item	Treatments				SEM[1]	P-value		
	L1	L2	H1	H2		Energy	LPL	E X L
Tri-glycerides, mg/dL								
Initial	36	36	36	36				
2 week	52.2	57.4	43.6	64.2	3.80	0.90	0.10	0.31
5 week	47.6	62.4	67.8	66.8	3.44	0.07	0.29	0.22
10 week	40.4	35.6	40.8	40.2	2.95	0.70	0.68	0.74
Total cholesterol, mg/dL								
Initial	159	159	159	159				
2 week	72.6	93.4	74.4	73.0	3.23	0.11	0.10	0.06
5 week	79.8	76.6	92.4	82.4	2.21	0.03	0.10	0.38
10 week	55.8	68.4	74.6	66.4	2.84	0.12	0.68	0.06
LDL[1] cholesterol, mg/dL								
Initial	104.4	104.4	104.4	104.4				
2 week	37.4	42.4	32.4	28.6	2.04	0.02	0.87	0.24
5 week	43.6	36.6	50.6	42.8	1.61	0.02	0.01	0.87
10 week	20.2	33.8	41.2	29.8	3.14	0.15	0.85	0.04
HDL[2] cholesterol, mg/dL								
Initial	42.8	42.8	42.8	42.8				
2 week	17.6	21.6	21.8	20.4	0.64	0.20	0.26	0.03
5 week	22.4	24.2	26.2	26.8	0.73	0.03	0.38	0.66
10 week	26.6	24.4	23.2	24.0	1.21	0.46	0.78	0.57
HDL:LDL ratio								
Initial	0.41	0.41	0.41	0.41				
2 week	0.47	0.51	0.67	0.71	0.64	0.20	0.26	0.03
5 week	0.51	0.66	0.52	0.63	0.72	0.03	0.38	0.66
10 week	1.32	0.72	0.56	0.81	1.21	0.46	0.78	0.57
BUN[3], mg/dL								

Initial	12.5	12.5	12.5	12.5				
2 week	15.14	9.22	14.1	14.6	0.80	0.11	0.06	0.02
5 week	10.48	11.58	12.5	13.4	0.32	0.01	0.05	0.78
10 week	12.10	11.16	9.62	7.8	0.55	0.01	0.13	0.62

[1]Standard error of the mean.

[2] LDL : Low density lipoprotein

[3] HDL : High density lipoprotein

[4] BUN : Blood urea nitrogen

Table 6. The effect of dietary energy levels and LPL supplementation on feed cost/weight gain.

Items	L1	L2	H1	H2
Phase I (0 to 2 weeks)				
Price of feed (won/kg)	657	659	658	660
Feed intake per head (kg/pig)	6.65	6.42	7.07	6.66
Feed cost per head (won/pig)	4,368	4,229	4,651	4,394
Weight gain per head (kg/pig)	3.89	3.79	3.53	3.52
Feed cost/weight gain (won/kg)	1,123.1	1,117.2	1,316.3	1,249.8
Index	100.0	99.5	117.2	111.3
Phase Ⅱ (2 to 5 weeks)				
Price of feed (won/kg)	545	547	546	548
Feed intake per head (kg/pig)	13.81	12.92	13.92	15.26
Feed cost per head (won/pig)	7,529	7,067	7,599	8,363
Weight gain per head (kg/pig)	7.63	8.02	7.91	8.35
Feed cost/weight gain (won/kg)	986.2	880.9	960.0	1001.8
Index	100.0	89.3	97.3	101.6
Phase Ⅲ (5 to 10 weeks)				
Price of feed (won/kg)	437	438	433	434
Feed intake per head (kg/pig)	30.71	28.15	33.28	33.20
Feed cost per head (won/pig)	13,420	12,329	14,410	14,408
Weight gain per head (kg/pig)	18.61	21.47	19.85	22.87
Feed cost/weight gain (won/kg)	760.7	607.1	779.8	678.2
Index	100.0	79.8	102.5	89.1
Total (0 to 10weeks)				

Feed cost per head (won/pig)	26,054	23,638	27,724	28,264
Weight gain per head (kg/pig)	30.13	33.28	31.29	34.74
Feed cost/weight gain (won/kg)	864.7	710.3	886.0	813.6
Index	100.0	82.1	102.4	94.0

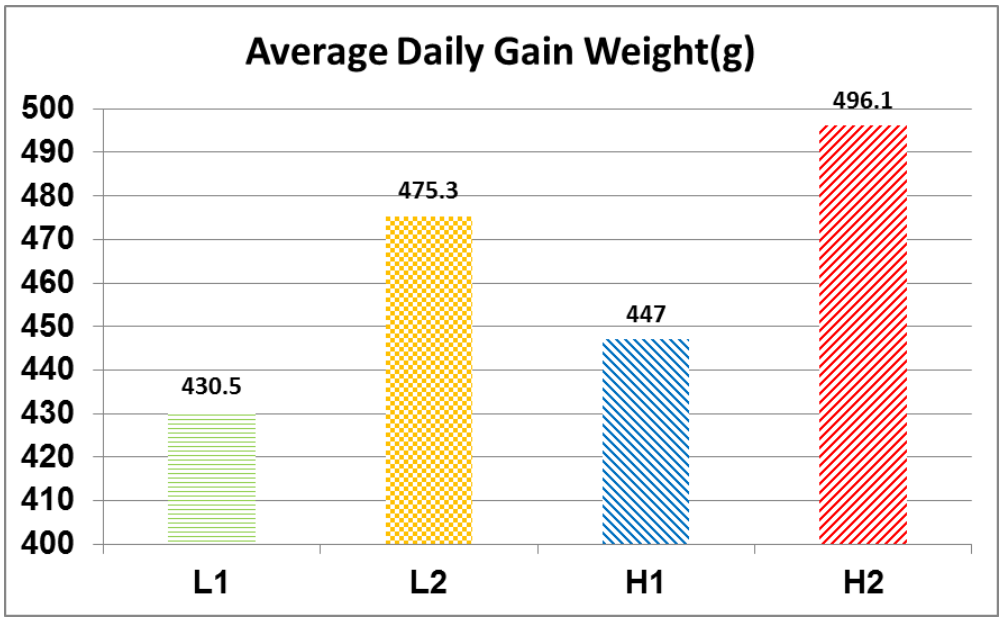

Figure 1. Comparison of average daily gain weight

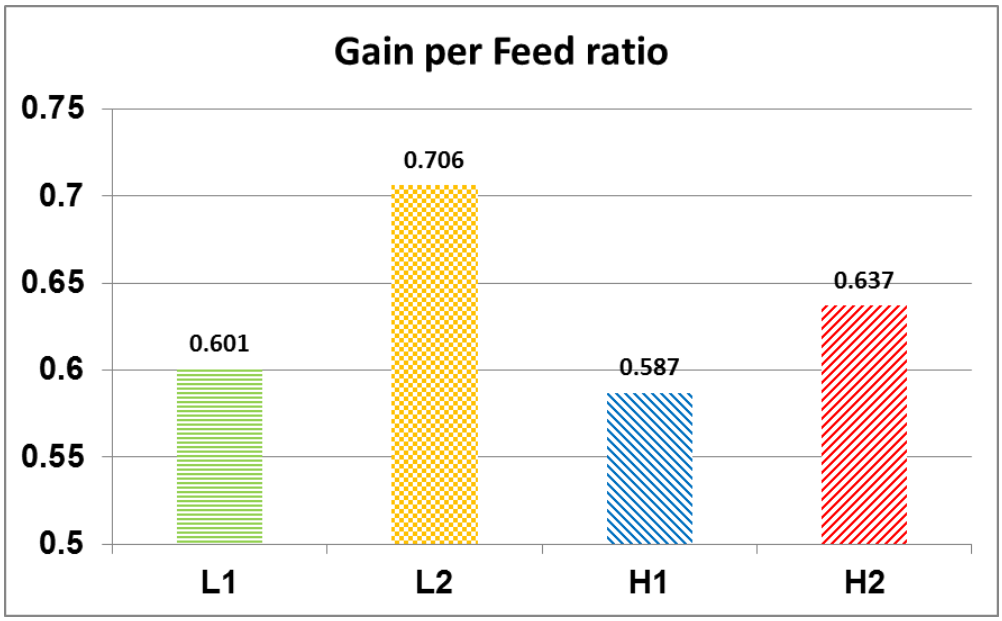

Figure 2. Comparison of gain per feed ratio

IV. Effects of different energy and LPL supplementation in late gestating and lactating sows

Abstract: This study was conducted to estimate the effects of different energy levels and LPL supplementation in sow diets from late gestating period to lactating period on the performance of sows and their progeny. A total of 60 F1 (Yorkshire × Landrace) sows at d 90 day of gestation were assigned to 4 treatments, 15 replications by CRD. Treatments were divided by dietary energy levels and LPL supplementation levels in factorial arrangements. First factor was energy level (3,300 kcal of ME/kg or 3,200 kcal of ME/kg) and second factor was LPL level (0 or 0.05%). There were no differences on body condition, WEI and ADFI in lactation sows. Rectal temperature of gestating sows (d 110) was increased by increment of energy level and LPL supplementation ($P<0.01$ and $P<0.01$, respectively). Although there was no difference in reproductive performance, interaction between energy and LPL supplementation was observed at parturition. High energy treatments (H1 and H2) showed higher number of total born and born alive while low energy treatments (L1 and L2) had lower number of total born and born alive (E×X, $P=0.06$ and $P=0.06$, respectively). Litter weight and piglet weight did not show any

difference during lactation period, but litter weight gain tended to increase in high energy treatments (P=0.06). Dietary energy level or LPL supplementation had no influence on composition of colostrum and milk (21d). As dietary energy level increased, serum insulin level of lactating sows (21d) was increased (P=0.03). Glucose level was decreased by LPL supplementation at d 110 of gestation (P<0.05). There were no significant effects on IgG and IgA at 24 hrs postpartum, but 0.05% LPL treatment showed lower IgG level than 0% LPL treatments in suckling piglets at d 21 of postpartum (P<0.01). In conclusion, there were no differences on reproductive performance and litter performance in their progeny although 100 kcal of ME/kg was reduced in sow's diets. However, current study showed positive responses in number of piglets and litter weight gain at d 21 of lactation numerically as energy level increased (P=0.18 and P=0.06, respectively).

Key words: Energy, LPL (lysophophospolipids), Sow, Reproductive performance, Litter performance.

INTRODUCTION

Reproduction potential of sows has been improved in recent years. PSY 24.8 in Canadian pigs was presented and top 10% of them reached PSY 27.5 (Williams et al., 2011). In these days, high ranked pig farms reached PSY 30 (Pinder, 2007). As MSY and PSY improved, energy requirement of sows' diet becomes more important. NRC (2012) recommended the higher energy requirement of ME 3,300kcal/kg in sow diet than ME 3,265kcal/kg from NRC (1998). Many studies showed high energy level of gestating sows' diet increased body weight of gestating sow and decreased ADFI in lactating period (Dourmad et al., 1991; Revell et al., 1994; Weldon et al., 1994). Low ADFI in lactating period decreased milk yield and increased piglet mortality (Long et al., 2010). On the other hand, a few studies showed increased dietary energy content from gestating period to lactating period improved milk production and milk quality (Pettigrew, 1981; Drochner, 1989; Chilliard, 1993), and lipid supplementation in lactating period decreased back fat loss after lactation, WEI, and increased number and weight of weaning pigs (Reese et al., 1982a,b; Chilliard, 1993).

LPL increases digestibility of lipid in animal (Davis, 1990, Jones et al., 1992), so it can be a solution for improving energy utilisation. Some studies demonstrated that LPL supplementation improved lipid digestibility (Superchi et al.,

1996; Jin et al., 1998) and protein digestibility (Jones et al., 1992; Dierick and Decuypere, 2004). Unfortunately, most studies were dealing with weaning pigs or growing-finishing pigs and only few sow experiments were conducted about effect of LPL supplementation. Therefore, this research was conducted to estimate the effects of different dietary energy level and lysophospholipids supplementation on body condition, reproductive performance, litter performance, milk composition, and blood profiles in late gestating to lactating sows and their progeny.

MATERIALS AND METHODS

Animal and housing environment

A total of 60 late gestating sows (F1, Yorkshire × Landrace, Darby, Korea) with an initial BW of 229.28 ± 8.86kg were used at a research farm located in Eum-seong, Korea. Sows were allotted to 4 treatments based on BW and backfat thickness with 15 replications (1 pig per replication) in a completely randomized design (CRD). Sows were in gestation stall (2.4 × 0.64 m) until d 110 of gestation, and moved to farrowing crate (2.5×1.8 m) from d 110 of gestation to weaning. Sows in second and more than 3rd parity were fed 2.2kg/day and 2.4kg/day of experimental diet, respectively in gestating period and lactating sows were fed commercial lactation diet restrictively during 5 days postpartum (increase of 1 kg/d)

then lactating sows were fed diet *ad libitum.* Piglets were cross-fostered within treatments before 1 day after birth to balance suckling intensity of sows with equalization of litter size, and thus to minimize any affect of initial litter size potentially affecting litter growth. Within 24 hrs postpartum, Fe-dextran (150 ppm) injection, ear notching, needle teeth clipping and tail docking were practiced to litters of sows. After 3 days of partum, male piglets were castrated. During lactation, the room temperature and air condition of farrowing barn were kept automatically at 27±3℃ by heating lamps and ventilation fans and air-conditioner in farrowing barn. After weaning, sows were moved to breeding barn.

Experimental design and diet

Treatments were designed with 2 × 2 factorial arrangements according to dietary energy levels and LPL supplementation levels. First factor was dietary energy levels (3,300 kcal of ME/kg or 3,200 kcal of ME/kg) and the second factor was supplementation of LPL (Supplementation levels: 0 or 0.05%). The experimental diets were consisted of a corn-soybean meal based diet. Crude protein and lysine contents in diets for gestating sow were 12.90% and 0.74%, and lactating sows' diets were 16.80%, and 1.05%, respectively. Other nutrient requirements were met or exceed by NRC (1998). LPL was used with 25% emulsifier product of

Kemin corporations. Ingredients and chemical compositions of experimental diets were presented in Table 2 and 3.

► **Experimental design**

Factors	Supplementation level			
Energy	ME, 3,200 kcal/kg		ME, 3,300 kcal/kg	
LPL	0%	0.05%	0%	0.05%

L1 : Energy 3,200 kcal of ME/kg + 0% LPL

L2 : Energy 3,200 kcal of ME/kg + 0.05% LPL

H1 : Energy 3,300 kcal of ME/kg + 0% LPL

H2 : Energy 3,300 kcal of ME/kg + 0.05% LPL

Measurements

Body weight, backfat thickness (P_2 position) and their changes of sows were measured at d 90 and d 110 of gestation, 24 hrs postpartum and d 21 of lactation. When measuring backfat thickness at P_2 position (mean value from both side of the last rib and 65 mm away from the backbone), an ultra-sound device (Lean meter, Renco Corp., Minneapolis, USA) was used. Rectal temperature of sows was measured by thermometer (polygreen Co. Ltd) at d 90 and d 110 of gestation, and 24 hrs postpartum and d 21 of lactation to check their health condition.

The numbers of total born, still born, and born alive were recorded within 24 hrs postpartum and the number of piglets during lacation experiment was recorded after cross-fostering and at d 21 of lactation. The weight of pigs was recorded before cross-fostering and at d 21 of lactation. Feed intake was recorded daily by the end of d 21 of lactation. Weaning to estrus interval (WEI) was determined by checking the days for estrus after weaning.

The colostrum and milk were collected at 12 hrs postpartum and d 21 of lactation by an injection of oxytocin 0.3ml (10 IU/ml), and collected milk samples were stored -20℃ until analysis. Collected colostrum and milk were analyzed with MilkoScan (FT20, FOSS Electric Co., Denmark) to estimate milk fat, protein, lactose, total solid and solids not fat (SNF).

Blood samples of sows was collected in serum tube (serum tube, BD Vacutainer®) at d 90 and d 110 of gestation, and 12 hrs postpartum and d 21 of lactation and centrifuged 3,000rpm, 4℃ for 15 minutes. After sample centrifuged, serum was collected in micro-tube at –20℃ until analysis. Blood serum was analyzed with blood analyzer (Ciba-Corning model, Ciba Corning Diagnostics Co.) to estimate insulin and glucose. In piglets, blood samples were collected from anterior vein of piglets at 24 hrs postpartum and d 21 of lactation and centrifuged 3,000rpm, 4℃ for 15 minutes. After centrifuge, serum was collected in micro tube at –20℃ until analysis. Blood serum was analyzed IgG and IgA contents by ELISA

method (Elisa Starter Accessory Package, pig IgG ELISA Quantification Kit, pig IgA ELISA Quantification kit; Bethyl, Texas, USA).

Statistical analysis

Statistical analysis was conducted by GLM (General Linear Model) of SAS (SAS Institute, 2004), and each sow and suckling piglet were allotted to dietary treatments based on energy levels and LPL supplementation levels in completely randomized design (CRD). Statistical analysis was conducted with ANOVA in GLM procedure, and LSD (Least Significant Difference) was used to compare means in 2×2 factorial arrangements. PDIFF option of SAS was used to compare between analysis results. If P value was less than 0.05, it was thought to have significant difference and if lower than 0.01 to have highly significant difference. When P value lies between 0.05 and 0.10, it was thought to have tendency.

RESULTS AND DISCUSSION

Body weight, backfat thickness, WEI, ADFI

The effect of different energy and LPL level on body weight, back-fat thickness, WEI, ADFI and rectal temperature in late gestating to lactating sows were shown in Table 4 and 5. There were no differences in body weight and body weight

changes during whole experimental period. Backfat thickness and its changes showed no differences in whole period. ADFI and WEI also did not show any difference among treatements.

Long et al. (2010) observed that feeding different levels of energy (6,330-6,930 kal of ME/day) in sow diet did not show any difference on BW at d 110 of gestation among treatements. According to Rosero et al. (2015), they increased fat concentration (3.4%-9.2%) and energy values (3.24-3.53 Mcal/kg) in lactating sow diets, however the results didn't show any differences on BW at d 21 of lactation and BW change during overall lactation. These results are in agreement with findings of current study. Considering the previous studies (Long et al., 2010; Jones et al., 1992; Overland et al., 1993, 1994; Rodas et al., 1995; Xing et al., 2004), different energy and LPL level did not affect on BW, BW change and feed intake throughout the lactation period.

The supplementation of LPL treatment presented the lowest backfat loss during lactating period numerically (P=0.4) (Figure 2). It is thought that supplementation of LPL improved the utilization of dietary energy. Sows with insufficient feed intake use nutrients accumulated in body to yield milk so decrease in body weight (Dourmad et al., 1994). Improving lipid digestibility by LPL supplementation, it conserves the lipid deposition rather than lipid mobilization.

Poor body condition from insufficient feed intake in lactation leads to increase WEI (King and Williams, 1984; Baidoo et al., 1992), to decrease ovulation rate (Foxcroft et al., 1995). However, Reese et al. (1982) reported that there was no difference in WEI of sows fed 12 MJ of ME/d or 16 MJ of ME/d. Their result was in agreement with current study. In this stuty, we didn't find any WEI difference. It may suggest that WEI is not affected in these energy levels (ME 3,200~3,300 Kcal/kg).

Total energy requirements in lactating sows are related with the sum of requirements for maintenance and those for milk production (Noblet et al., 1990). ADFI during lactation may be affected by body condition and litter weight through the whole lactation period. According to Eisen et al. (2002), a higher daily feed intake during lactation reduced tissue loss of the sow and increased litter weight gain.

Therefore, the finding for higher feed intake numerically (P=0.19) during lactation in sows fed higher energy treatments (H1, H2) may be caused by their bigger litter size in this experiment. The interaction between energy level and LPL supplementation during lactation was not clear in this study because of different feed intakes. In the meantime, there was no difference between H1 and H2 in reproductive performance and litter performance. One possible reason may be that H1 treatment had enough energy to keep their body condition and increase litter weight gain, resulting in similar feed intake with H2 treatment.

Rectal temperature

High energy diets and LPL supplemented treatments had higher rectal temperature at d 110 of gestation ($P<0.01$ and $P<0.01$, respectively). In addition, interaction between energy and LPL was found ($P<0.01$) in rectal temperature. L2 (low energy treatment with LPL) showed higher rectal temperature compared with L1 (low energy diet without LPL).

In lactation period, there were significant effects of energy level and LPL supplementation at 24 hrs postpartum ($P=0.04$ and $P<0.01$, respectively). Interaction between factors was also found ($P=0.04$) at 24 hrs postpartum. When LPL was supplemented, high energy treatment (H2) showed huge reduced rectal temperature and low energy treatment (L2) showed little reduced rectal temperature. Interaction was found at d 21 of lactation ($P<0.01$), and LPL treatment showed increase of rectal temperature in 3,200 kcal of ME/kg. However, H2 (LPL supplementation with 3,300 kacl of ME/kg treatment) showed decrease of rectal temperature.

King et al. (1972) reported that a low rectal temperature was present for at least eight days pre-partum and also pre-farrowing sows have a slightly lower body temperature and maybe a corresponding higher metabolic rate. They also found that with the stress of giving birth and the beginning of lactation, body temperature increases followed by a supposed decrement in metabolic rate. According to

William and Hendrix (1978), their results also showed that elevated rectal temperatures of sows were maintained for at least 24 hrs after parturition, however, the observed temperature was in the normal range.

Rectal temperature is the most common method to estimate body temperature of pigs (Gourdine et al., 2007). The result of present study was similar to other research with high energy diet increasing heat production (Williams et al., 2014). According to Williams et al. (2014), lactating sows fed high energy diet showed higher body temperature because of heat production from the high energy. The result of them is corresponding to current study. In this study, rectal temperature rose as energy increased ($P<0.01$). Therefore, it is considerd that since energy utilization increased with LPL supplement, rectal temparture might increase ($P<0.01$).

Reproductive performance and litter performance

The effects of different energy levels and lysophospholipids supplementation from late gestating to lactating sows on reproductive performance and litter performance were shown in Table 5. Interaction between energy levels and LPL supplementation was observed in number of total born and born alive (ExL, $P=0.06$ and $P=0.06$, respectively). H2 showed higher number of total born and born

alive while L2 showed lower number of total born and born alive compared with H1 and L1 respectively (E×L, *P*=0.06 and *P*=0.06, respectively).

Also, the sows fed high energy diet had a tendency of higher number of born alive (*P*=0.09). However, unfortunately the number of piglet/litter is usually affected from the early gestating period (Kim et al., 2011), so differences of energy and LPL supplementation level in the late gestating period in this study had no effect on the number of piglets. In litter performance, there was no difference in litter weight and piglet weight at after cross-fostering and d 21 of lactation. However, sows fed high energy diets tended to increase litter weight gain rather than sows fed low energy diets (*P*=0.06).

The consistent results for interaction between dietary energy content and litter weight gain were not available untill now. Frobish et al. (1973) showed 5,400 or 10,800 kcal of ME per day had no effect on litter weight but Libal and Wahlstrom (1977) showed high amount of feed intake could increase total litter weight.

Although number of piglet at d 21 of postpartum showed no difference, H2 (ME 3,300 kcal + 0.05% LPL) showed the highest number of piglet at d 21 of postpartum numerically (*P*=0.18). High energy treatments (H1 and H2) showed 0.43 higher number of piglets than low energy treatments (L1 and L2), and 0.05% LPL supplemented treatments (L2 and H2) showed 0.17 higher number than non-supplemented groups. Rosero et al. (2012) also found ME 3,350 kcal in lactating

diet showed 0.31 higher numbers of piglets than those of ME 3,260 kcal treatment. Because milk yield needs lots of energy (Boyd and Kensinger, 1998), higher energy content in lactating sow diet increases milk yield to prevent from mortality of suckling piglets. Noblet and Etienne (1986) also reported that milk yield measured every 4 days was lower in the low energy group (ME 10.2 Mcal) compared with higher energy group (ME 14.2 Mcal). According to them, the ability of sows to mobilize body fats in order to maintain the output of energy in milk was reduced as body fat reserves were depleted. This result shows similar trend with this current study even though there was no difference between low energy and high energy.

Litter weight had no difference at 24 hrs postpartum and d 21 of lactation. However, litter weight gain tended to increase in high energy treatments (P=0.06) (Figure 1). Rosero et al. (2012) already represented that dietary energy level had no significant effects on litter weight at weaning but there was numerical increase of 4.8%. In litter weight gain, L2 (ME 3,200 with LPL treatment) showed 7.6% higher litter weight gain than L1 (without LPL) and H2 (ME 3,300 with LPL treatment) showed 5.6% higher litter weight gain. Because of the fact that increased energy level or energy utilization improved milk yield (Boyd and Kensinger, 1998), it is thought that H2 (ME 3,300 kcal/kg + 0.05% LPL treatment) resulted in the highest litter weight and litter weight gain numerically among 4 groups.

Milk composition

The effect of different energy and LPL supplementation on milk composition of lactating sows was shown in Table 6. In this study, dietary energy level and LPL supplementation had no effects on composition of colostrum and milk. Generally, milk composition is changed according to breed, body condition or nutritional compositions of feed (Klaver et al., 1981; Jackson et al., 1995; Daza et al., 2004) and it affects the growth of piglets.

In other studies, Long et al. (2010) suggested that there was no significant effect of energy level (ME 3,165-3,465 kcal/kg) on colostrum and milk quality. Coffey et al. (1982) reported that milk yield at d 14 of lactation was increased (P<0.05) approximately 30% by the addition of lipids to sow diets but there were no treatment differences in milk compositions including crude protein, lactose, total solids and solids-nonfat from 10.2 to 14.2 Mcal ME. Although LPL supplementation increased energy utilisation (Zhao et al., 2015), different energy levels did not show any difference since they were within the range not affecting milk compositons (Long et al., 2010). So, dietary energy level (ME 3,200-3,300 kcal/kg) and LPL levels (0, 0.05%) had no influence on colostrum composition and milk (21d) composition.

Blood profiles of sows

The effect of different energy levels and LPL supplementation on blood profiles of late gestating and lactating sows was presented in Table 7.

The concentration of insulin had no significant difference at d 110 of gestation and 24 hrs postpartum but insulin level increased as dietary energy level increased in d 21 of lactation (P=0.03). The H2 (3,300 kcal of ME/kg + 0.05% LPL treatment) showed the highest level of insulin (P<0.05). There was tendency of interaction between energy and LPL level (P=0.08). In high energy level, insulin level increased with LPL supplementation and insulin level decreased when LPL supplemented in low energy diet.

The concentration of glucose showed a significant difference in d 110 of gestation (P=0.04). The sows fed the diet with LPL showed lower glucose levels at d 21 of postpartum numerically (P=0.11). In contrast, sows fed the diet with LPL supplemented showed a trend that serum glucose level was increased (P=0.09).

Insulin level is related to metabolism in breast, body and lipid synthesis (Fulks et al., 1975; Schams et al., 1994), and higher energy levels (H1 and H2) seems to improve lipid metabolism and lipid synthesis of lactating sows because higher level of insulin was observed in sows fed high energy (H1 and H2) at d 21 of lactation (P<0.03)

Increasing milk yield in lactating period decreased glucose level in some studies (McNamara and Pettigrew, 2001). There was no significant effect on glucose

level with milk production in this study. In conclusion, although supplementation of LPL decreases glucose level at d 110 of gestation, there is no negative effect on glucose concentration related with milk yield in lactating period.

Immunity of piglets

The effect of different energy and LPL supplementation on immune component of piglets was present in Table 8. There was no significant difference in serum IgA of 24 hrs postpartum and at d 21 of lactation. Serum IgG concentration at d 21 of lactation showed no difference among treatments, but there was a significant difference in IgG level at d 21 of lactation ($P<0.01$) and 0.05% LPL treatments showed a lower IgG level than 0% LPL treatments.

Immunity of piglet is derived from colostrum or milk of sow (Blecha, 2001), and piglets can synthesize immunoglobulin at d 35 of postpartum (Carney et al., 2013). Klobasa et al. (1981) showed deficiency of IgG intake can increase mortality of piglets. Thus immunoglobulin intake from sow is very important action for suckling piglets.

The formation of IgA following local stimulation has been verified in sheep mammary tissue (Lascelles and McDowell, 1970) and fast IgG and IgM antibodies are also present in milk from stimulated glands (Outteridge et al., 1968). IgA is the main immunoglobulin of sows' milk (Porter et al., 1970; Curtis and

Bourne, 1971), even though IgA present in colostrum is only a minor component, IgG constituting over 80% of total colostral immunoglobulin (Porter, 1969; Curtis and Bourne, 1971).

So far there are few LPL studies on suckling piglets' immunity. Although supplementation of LPL decreased IgG level in blood of 21 days old piglet but there was no difference in piglet growth performance. Therefore, it seems that there was no negative effect of LPL on immunity of piglet but more research will be needed.

CONCLUSION

This study showed no significant effects on sows and litter performance, milk composition and blood profiles, depending on dietary energy levels and lysophospholipids supplementation. As well, piglet weight and weight gain during lactation were not affected by dietary energy levels and supplementing LPL. On the contrary, supplementation of lysophospholipids showed the lower concentration of IgG in blood profiles in suckling piglet at d 21 of lactation even though it didn't influence on their performance. Higher energy and lysophospholipids supplementation also affected rectal temperature at d 110 of gestation period.

In conclusion, this experiment demonstrated that different energy levels and LPL supplementation during late gestation and whole lactation period did not

show any difference in sow performance. However, further studies would be needed to prove the clearer effects of dietary LPL on energy utilization in sow diets.

Table 1. Ingredients and chemical compositions of experimental diet in gestating sow[1]

Energy	**ME, 3,200 kcal**		**ME, 3,300 kcal**	
LPL	**0%**	**0.05%**	**0%**	**0.05%**
Ingredient, %				
Corn	75.96	76.00	73.05	73.09
SBM[4]	12.30	12.30	12.75	12.76
Tallow	0.70	0.70	3.10	3.10
Wheat bran	4.81	4.67	4.89	4.76
Rapeseed meal	2.12	2.17	2.12	2.15
L-lysine	0.30	0.30	0.29	0.29
DL-methionine	0.00	0.00	0.00	0.00
MDCP[5]	2.16	2.16	2.15	2.15
Limestone	1.05	1.05	1.05	1.05
Vit. Mix[2]	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10
Choline chloride-50	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
LPL[4]	0.00	0.05	0.00	0.05
Total	100.00	100.00	100.00	100.00
Chemical composition				
ME	3,200.00	3,200.00	3,300.00	3,300.01
CP[6]	12.90	12.90	12.90	12.90

Lys	0.74	0.74	0.74	0.74
Met	0.20	0.20	0.20	0.20
Ca	0.90	0.90	0.90	0.90
Total P	0.70	0.70	0.70	0.70

[1] Treatment L1(3,200 kcal of ME/kg + 0 % LPL), Treatment L2(3,200 kcal of ME/kg + 0.05 %LPL), Treatment H1(3,300 kcal of ME/kg + 0 % LPL), Treatment H2(3,300 kcal of ME /kg + 0.05 % LPL). Lysolecithin content 25% from Kemin Industries.

[2] Vitamin Mix. Provided per kg of diet: Vit A, 16,000IU; Vit D3, 3,200IU; Vit. E, 35IU; Vit. K3, 5mg; Rivoflavin, 6mg; Calcium 288mg; Pantothenic acid, 16mg; Niacin, 32mg; d–Biotin, 128ug; Vit.B12, 20ug.

[3] Mineral Mix. Provided per kg of diet: Fe, 281mg; Cu, 143mg; Mn, 49mg; I, 0.3mg; Se, 0.3mg.

[4] LPL(lysophospholipids): lysolecithin content 25%, Kemin, South Korea.

[5] SBM : Soybean meal

[6] MDCP : Mono di-calcium phosphate

[7] CP : Crude protein

Table 2. Ingredients and chemical compositions of experimental diet in lactating sow[1]

Energy	**ME, 3,200 kcal**		**ME, 3,300 kcal**	
LPL	**0%**	**0.05%**	**0%**	**0.05%**
Ingredient, %				
Corn	64.02	64.04	61.18	61.20
SBM[5]	23.77	23.82	24.24	24.29
Tallow	1.49	1.49	3.87	3.87
Wheat bran	6.70	6.58	6.70	6.58
L-lysine	0.38	0.38	0.37	0.37
DL-methionine	0.01	0.01	0.01	0.01
MDCP[6]	1.98	1.98	1.98	1.98
Limestone	1.05	1.05	1.05	1.05
Vit. Mix[2]	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10
Choline chloride-50	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
LPL[4]	0.00	0.05	0.00	0.05
Total	100.00	100.00	100.00	100.00
Chemical composition				
ME	3,200.05	3,200.08	3,300.05	3,300.08
CP[7]	16.80	16.80	16.80	16.80
Lys	1.05	1.05	1.05	1.05
Met	0.25	0.25	0.25	0.25

Ca	0.90	0.90	0.90	0.90
Total P	0.70	0.70	0.70	0.70

[1] Treatment L1(3,200 kcal of ME/kg + 0 % LPL), Treatment L2(3,200 kcal of ME/kg + 0.05 %LPL), Treatment H1(3,300 kcal of ME/kg + 0 % LPL), Treatment H2(3,300 kcal of ME /kg + 0.05 % LPL). Lysolecithin content 25% from Kemin Industries.

[2] Vitamin Mix. Provided per kg of diet: Vit A, 16,000IU; Vit D3, 3,200IU; Vit. E, 35IU; Vit. K3, 5mg; Rivoflavin, 6mg; Calcium 288mg; Pantothenic acid, 16mg; Niacin, 32mg; d–Biotin, 128ug; Vit.B12, 20ug.

[3] Mineral Mix. Provided per kg of diet: Fe, 281mg; Cu, 143mg; Mn, 49mg; I, 0.3mg; Se, 0.3mg.

[4] LPL(lysophospholipids): lysolecithin content 25%, Kemin, South Korea.

[5] SBM : Soybean meal

[6] MDCP : Mono di-calcium phosphate

[7] CP : Crude protein

Table 3. Effect of energy and LPL level on body weight, back-fat thickness, WEI and ADFI in late gestating to lactating sows

Energy level	ME 3,200 kcal		ME 3,300 kcal		SEM[1]	P-value		
LPL	0%	0.05%	0%	0.05%		E	L	E×L
Body weight (kg) of gestating sows								
Day 90	229.1	229.6	228.6	229.9	2.91	0.99	0.88	0.95
Day 110	241.7	247.1	244.0	242.1	3.23	0.84	0.79	0.58
Day 90 to 110	12.6	17.5	15.4	12.2	1.30	0.80	0.70	0.40
Body weight (kg) of lactation sows								
24 hrs postpartum	219.9	218.6	211.4	217.4	3.01	0.43	0.70	0.55
Day 21 of lactation	217.1	213.4	207.9	215.6	3.46	0.62	0.78	0.42
Farrowing to 21 d	- 2.8	- 5.2	- 3.5	-1.8	1.54	0.66	0.90	0.52
Back-fat thickness (mm) of gestating sows								
Day 90	19.4	19.7	19.1	20.2	0.60	0.94	0.61	0.75
Day 110	20.2	19.7	19.5	20.5	0.67	0.97	0.88	0.57
Day 90 to 110	0.8	0.0	0.4	0.3	0.32	0.67	0.67	0.98
Back-fat thickness (mm) of lactating sows								
24 hrs postpartum	18.6	19.3	19.8	19.0	0.65	0.77	0.96	0.57
Day 21 of lactation	17.3	18.4	17.9	18.1	0.76	0.92	0.69	0.76
Farrowing to 21 d	-1.3	- 0.9	-1.9	- 0.9	0.40	0.76	0.40	0.73
Weaning to estrus interval (day)								
	4.4	4.5	4.6	4.6	0.09	0.48	0.76	0.74
Average daily feed intake(lactation period), kg/d								
Farrowing to 21 d	5.73	5.84	5.58	5.19	0.15	0.19	0.66	0.41

[1] Standard error of the mean.

Table 4. Effect of energy and LPL level on rectal temperature in late gestating to lactating sows

Energy level	ME 3,200 kcal		ME 3,300 kcal		SEM[1]	P-value		
LPL	0%	0.05%	0%	0.05%		E	L	E×L
Rectal temperature (°C) of gestating sows								
Day 90	37.8	37.8	37.8	37.8	-	-	-	-
Day 110	37.6^{C}	38.2^{B}	38.1^{B}	38.4^{A}	0.05	<0.01	<0.01	<0.01
Rectal temperature (°C) of lactating sows								
24 hrs postpartum	39.1^{B}	39.0^{B}	39.6^{A}	39.0^{B}		0.04	<0.01	0.04
Day 21 of lactation	39.1^{C}	39.8^{A}	39.5^{AB}	39.3^{BC}	0.08	0.87	0.14	<0.01

[1] Standard error of the mean.

^{ABC}means with different superscripts within the same row significantly differ (P<0.01)

Table 5. Effect of energy and LPL level on reproductive performance, litter performance in late gestating to lactating sows

Energy level	ME 3,200 kcal		ME 3,300kcal		SEM[1]	P-value		
LPL	0%	0.05%	0%	0.05%		E	L	E×L
Reproductive performance								
No. of piglets								
Total born/litter	13.60	11.87	13.13	14.93	0.46	0.15	0.97	0.06
Born alive	12.60	11.07	12.47	13.93	0.40	0.09	0.96	0.06
Stillbirths	1.00	0.80	0.66	1.00	0.15	0.75	0.92	0.46
After cross-foster	11.53	11.47	11.47	11.73	0.10	0.64	0.64	0.44
Day 21 of lactation	10.73	10.87	11.13	11.33	0.16	0.18	0.60	0.91
Litter weight, kg								
Litter birth weight	17.96	17.78	18.59	20.45	0.52	0.12	0.42	0.33
After cross-foster	16.15	17.57	16.88	16.93	0.38	0.96	0.34	0.38
Day 21 of lactation	56.11	60.57	62.74	65.35	1.90	0.14	0.35	0.81
Litter weight gain	39.96	43.00	45.86	48.42	1.80	0.06	0.68	0.67
Piglet weight, kg								
Piglet birth weight	1.39	1.55	1.45	1.38	0.03	0.43	0.55	0.10
After cross-foster	1.40	1.52	1.47	1.44	0.03	0.91	0.41	0.15
Day 21 of lactation	5.18	5.49	5.65	5.76	0.15	0.22	0.48	0.73
Piglet weight gain	3.78	3.97	4.18	4.32	0.14	0.17	0.56	0.94

[1]Standard error of the mean.

Table 6. Effect of energy and LPL level on milk composition of late gestating and lactating sows

Energy level	ME 3,200 kcal		ME 3,300kcal		SEM[1]	P-value		
LPL	0%	0.05%	0%	0.05%		E	L	E×L
Fat, %								
24 hrs postpartum	9.83	9.23	9.35	9.37	0.13	0.52	0.28	0.26
Day 21 of lactation	6.80	5.81	6.13	6.69	0.25	0.85	0.68	0.16
Protein, %								
24 hrs postpartum	10.24	10.25	10.27	10.29	0.19	0.94	0.98	0.99
Day 21 of lactation	4.81	4.86	4.72	4.86	0.07	0.76	0.55	0.80
Lactose, %								
24 hrs postpartum	9.17	9.09	9.03	9.11	0.31	0.93	0.99	0.91
Day 21 of lactation	6.17	6.25	6.32	6.26	0.04	0.31	0.92	0.38
Total solid, %								
24 hrs postpartum	4.30	4.32	4.31	4.30	0.11	0.98	0.99	0.96
Day 21 of lactation	19.10	18.34	18.76	19.42	0.28	0.55	0.94	0.25
Solid not fat, %								
24 hrs postpartum	20.62	20.61	20.61	20.60	0.57	0.99	0.99	0.99
Day 21 of lactation	11.18	11.25	11.05	11.15	0.08	0.49	0.60	0.94

[1]Standard error of the mean.

Table 7. Effect of energy and LPL level on blood profiles of late gestating and lactating sows

Energy level	ME 3,200 kcal		ME 3,300 kcal		SEM[1]	P-value		
LPL	0%	0.05%	0%	0.05%		E	L	E×L
Insulin (ug/L)								
Day 90	0.096	0.096	0.096	0.096		-	-	-
Day 110	0.051	0.043	0.047	0.053		0.71	0.91	0.35
24 hrs postpartum	0.120	0.162	0.095	0.156		0.70	0.21	0.80
Day 21 of lactation	0.129[b]	0.115[b]	0.160[b]	0.342[a]	0.03	0.03	0.12	0.08
Glucose (mg/dL)								
Day 90	82.00	82.00	82.00	82.00	-	-	-	-
Day 110	81.50[a]	72.75[b]	82.00[a]	78.00[b]	1.53	0.31	0.04	0.39
24 hrs postpartum	89.00	97.75	83.00	96.25	3.15	0.55	0.09	0.72
Day 21 of lactation	81.00	73.25	82.75	77.75	1.93	0.42	0.11	0.72

[1]Standard error of the mean.

[ab]means with different superscripts within the same row significantly differ (P<0.05)

Table 8. Effect of energy and LPL level on the immunity of piglets

Energy level	ME 3,200 kcal		ME 3,300 kcal		SEM[1]	P-value		
LPL	0%	0.05%	0%	0.05%		E	L	E×L
Immunoglobulin G, $5x10^4$/ul								
24 hrs postpartum	14.33	21.76	12.68	13.22		0.10	0.19	0.25
Day 21 of lactation	21.98	15.58	19.17	16.50	0.91	0.52	<0.01	0.22
Immunoglobulin A, $2x10^3$/ul								
24 hrs postpartum	106.95	118.89	148.30	118.10	7.38	0.17	0.52	0.16
Day 21 of lactation	0.24	0.20	0.18	0.16	0.04	0.59	0.69	0.89

[1]Standard error of the mean.

[ab]means with different superscripts within the same row significantly differ (P<0.05)

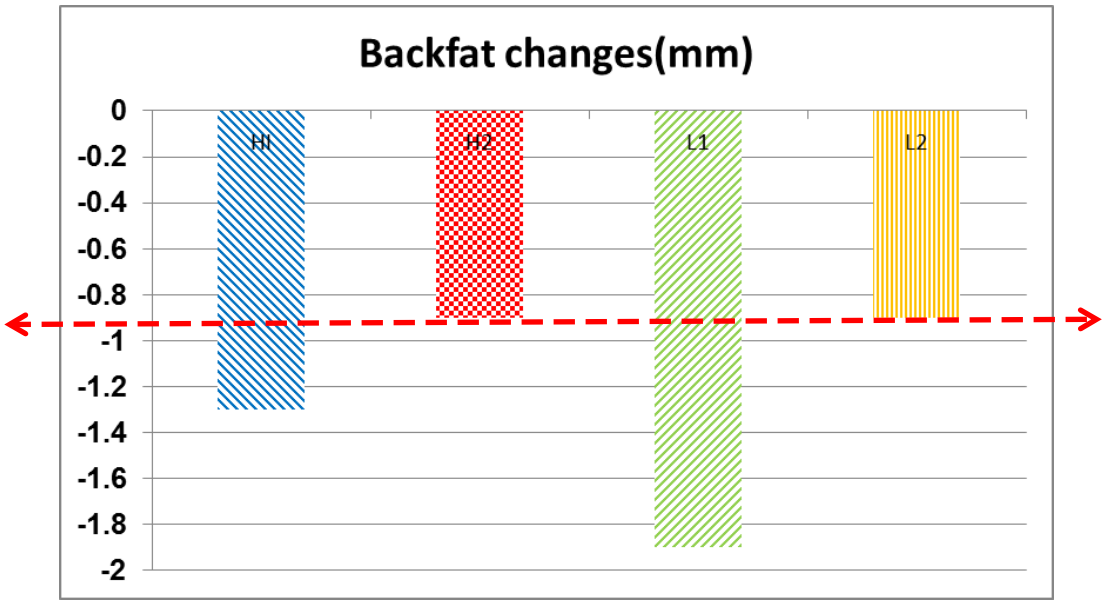

Figure 1. Comparison of backfat thickness change

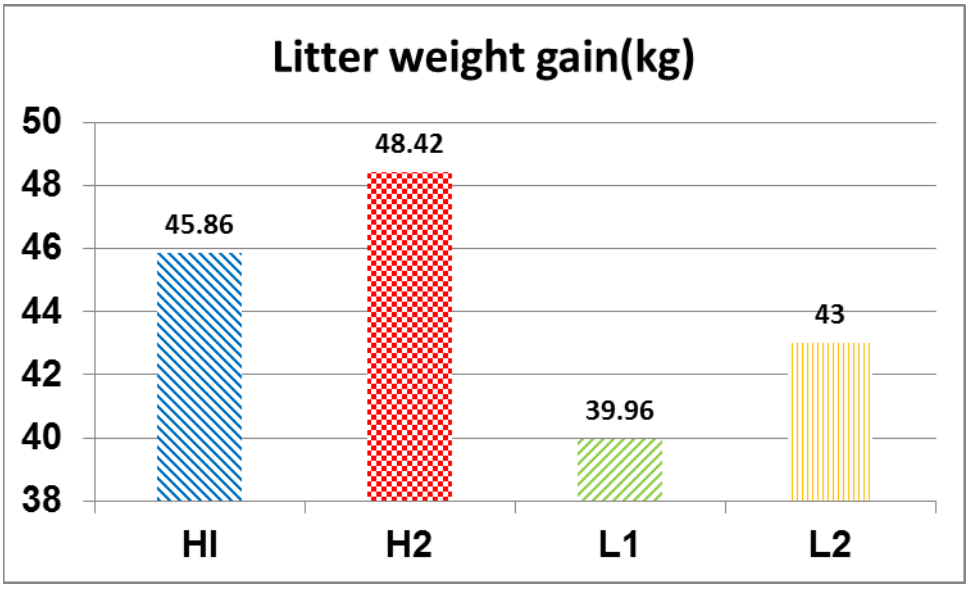

Figure 2. Comparison of litter weight gain

V. Effects of dietary LPL supplementation in nutrient digestibility on growing pigs

ABSTRACT : This experiment was conducted to evaluate the effect of dietary energy and LPL on nutrient digestibility in growing pigs. A total of 12 crossbred ([Yorkshire × Landrace] × Duroc) pigs with average 22.7±1.6kg were allotted to each treatment in an individual metablic crate to collect feces and urine separately. Growig pigs' nutrient digestibility trial was conducted to evaluate the nutrient digestibility and nitrogen retention in completely randomized design (CRD) with 3 replicates. Treatments were as followed: 1) ME 3,200 kcal/kg, 2) ME 3,200 kcal/kg with LPL supplementation, 3) ME 3,300 kcal/kg, 4) ME 3,300 kcal/kg with LPL supplementation.

All other nutrients in experimental diet were met or exceeded the NRC requirement (2012). The experimental diets were provided twice a day at 07:00 and 19:00. There were no differences in digestibility of dry matter, crude protein, crude fat and crude ash. In addition, there was also no difference in nitrogen retention. However, the amount of fecal N tended to increase as dietary energy level increases (P=0.06). Although fecal N showed linear difference in this experiment, the current study represented that nutrient digestibility and nitrogen retention rate were not affected by different energy levels and LPL supplementation. Therefore, it is

concluded that LPL supplementation and different energy levels did not affect nutrient digestibility of diets fed to growing pigs.

Key words: Growing pigs, Lysophospholipid, Nutrient digestibility, Nitrogen retention, Dietary energy

INTRODUCTION

Lipids and oils are very important dietary ingredients in animal production due to their high energy value (Bajao and Lara, 2005). However, we can't use the fat sources as much as we want in amimal diets since the process of fat digestion is more complicated than other nutrients. The limitation of fat digestibility is controlled by many factors including ages, sex, environments, and various species also have an effect on the lipid digestibility (Kussaibati et al., 1982). Most young animals are lack of production of natural pancreatic lipase and bile salts, so they have some problem in lipid digestion (Marzooqi et al., 1999). Dietary lysophospholipids are known to improve fat digestibility (Davis, 1990; Jones et al., 1992; Xing et al., 2004). Supplementing fat sources to the swine diets in weanning pigs have shown an increase in average daily gain and FCR during a nursing period (Cera et al., 1990; Howard et al., 1990; Li et al., 1990). There are many researches that dietary emulsifiers could increase fat digestibility and subsequently have an effect on growth performance in weaning pigs (Cera et al., 1990; Howard et al., 1990; Li et al., 1990; Xing et al., 2004). Some researchers observed that expecially LPL supplementation had a positive effect on lipid digestibility (Superchi et al., 1996; Jin et al., 1998) and protein digestibility (Jones et al., 1992; Dierick and Decuypere, 2004). According to Jones et al. (1992), fat digestibility was improved during a nursing period by supplementing lechitin or lysolechitin in the piglet diets including soybean oil or tallow. Thus, LPL supplementation could be one of solutions for improving energy utilization since LPL increases lipid digestibility in animal feeds (Davis, 1990; Jones et al., 1992). However, a few studies reported that threre was no improvement in growth performance and fat digestibility in weaning pigs with lecithin from soy (Overland et al., 1993a,b, 1994). Furthermore, Frobish et

al. (1969) observed that addition of emulsifying agents did not improve fat utilization. Therefore, the current study was conducted to evaluate the effects of LPL supplementation as an emulsifying agent on nutrient digestibility and nitrogen retention in growing pigs.

MATERIALS AND METHODS

Animal and housing

A total of 12 growing pigs ([Yorkshire × Landrace] × Duroc) averaging 22.7 ± 1.6kg were used in a digestibility experiment. A total of 12 pigs were allotted to each treatment in an individual metablic crate to collect feces and urine separately in a completely randomized design (CRD) with 3 replicates per treatment. The experimental diets were provided twice a day every 07:00 and 19:00 and water was provided to the pigs *ad libitum*. The trial consisted of an initial 6 day total collection period.

Treatment and experiment diet

Each treatment was designed based on different energy levels (3,200 or 3,300 kcal ME/kg) and LPL supplementation (0 or 0.05%) in a 2 x 2 factorial arrangement. All nutrients were met or exceeded NRC (2012) nutrient requirement. The formula and chemical compositon of experimental diets were presented in Table 1.

Sample collection and analysis

Total collection method was used to evaluate nutrient digestibility. The total amount of feed consumption and excreta of experimental pigs were recorded

daily for 3 days. The experimental pigs were fed same diet for reducing the variation of digestibility afer 3 days of feeding experimental diet term. The 1% chromic oxide was added in the experiment feeds as a marker during day 1 ~6 of collection term. Fecal collection was started when the first marker was emerged in the feces after 1 day feeding and finished when the final marker was shown up in the feces after 3 days feeding. Collected samples from each pig were put and sealed in plastic bags and kept frozen at -20C° until they were analyzed. And then, the samples were dried in an air-forced drying oven at 60C° for 72 h and weighted. Finally, they were ground into 1 mm particles in a Wiley mill for chemical analysis. Urine was collected daily through plastic container filled with 50 ml of 4N H_2SO_4 sulfuric acid for 6 days of collection term and total urine was completely stored -20C° and used for nitrogen retention analysis. Ground diets and fecal samples were analyzed for dry matter (DM) (967.03; AOAC, 1995); crude ash (923.03; AOAC, 1995); ether extract (920.39; AOAC, 1995), nitrogen by using the Kjeldahl procedure with Kjeltec (KjeltecTM 2200, Foss Tecator, Sweden) and calculated CP content (Nitrogen ×6.25;981.10; AOAC, 1995). Referring to the analyzed data and the digestibility of DM, crude fat, crude protein and crude ash were calculated.

< Calculation >

1. **Nutrient digestibility, %(DM basis)**

$$Digestibility(\%) = \frac{Nutrient\ \ intake\ \ - nutrient\ \ in\ \ feces}{Nutrient\ \ intake} \times 100$$

2. **Nitrogen retention, g/d**

Nitrogen retention (g/d) = N intake (g/d) – Fecal N (g/d) – urinary N (g/d)

Statistical analysis

The data were analyzed using ANOVA and means were separated by least significant difference (LSD) test using PDIFF option in the General Linear Model (GLM) procedure of SAS (SAS Institute, 2004). Individual sample pig was used as the experimental unit. Probability values less than 0.05 ($P<0.05$) were considered as significant difference; $0.05<P<0.10$ were indicative about some trend.

RESULTS AND DISCUSSION

The results of nutrient digestibility on different energy levels and LPL supplementation during digestibility experiment period were shown in Table 2. There was no difference in nutrient digestibility regardless of energy levels and LPL supplementation. The results of nitrogen retention also did not show any differences among treatments.

Dierick and Decuypere (2004) demonstrated that LPL supplementation improved fat digestibility in swine. According to Danek et al. (2005), when LPL was added in the piglet diet, fat digestibility was improved by 5~19% at the end of the first week of the experiment. However, when the fat digestibility was examined at

the end of fourth week, the increase of fat digestibility was less observable from 2.1% to 4.5% compared with the control group. It implicates that the effects of LPL on fat digestibility could be varied with pigs' age. According to Xing et al. (2004), improvement of growth performance in piglet did not appear to be related to nutrient digestibility because lysolecithin did not show improved nutrient digestibility. They did not suggest clear reason why there was contradiction between improved growth performance and no difference in nutrient digestibility. Other researchers also reported no singnificant difference in nutrient digestibility with emulsifier supplementation (Overland et al., 1993 and Overland et al., 1995). Furthermore, according to Soares and Lopez-Bote (2002), there was no positive effect on soybean oil, or lard digestibility of weaning pigs with lecithin supplementation in their experiments. Theses researches are in agreement with the results of the current study. There are various factors affecting nutrient digestibility. For example, endogenous losses, bacterial assimilation and nutrient vanishing by absorption in the digestive tract could affect fecal digestibility measurements but it doesn't mean that they have close relationship with post-absorptive utilization of nutrients (Xing et al., 2004). Therefore, fecal digestibility might not have clear relationship with the growth performance of pigs (Xing et al., 2004). These inconsistencies also could be casued by differences in emulsifiers and lipid sources fed in swine because different sources of emulsifiers and lipid might have different characteristics owing to the composition of fatty acid, different refinement and process and the the quantity of

emulsifying agents (Overland et al., 1995). Jones et al. (1990a) also reported that there was a negative effect of soy-lecithin on the digestibility of lard in young piglets and also no effect on coconut oil. However, they also found that fat digestibility increased by 9% more when tallow was added in the diets with lecithin and 4% more with lysolecithin. It implicates that the effect of emulsifiers could be dependent on various fat sources and the amount of emulsifiers used (Jones et al., 1990a).

CONCLUSION

This experiment represented that nutrient digestibility of dry matter, crude protein, crude fat, crude ash and nitrogen retention was not different with different energy levels and LPL supplementation. Therefore, different energy levels and LPL supplementation in growing pig diets do not have any effect on nutrient digestibility of diets fed to growing pigs.

Table 1. Ingredients and chemical compositions of experimental diet in 6-10 week

	Treatments[1]			
Ingredients,%	L1	L2	H1	H2
Corn	40.91	41.47	53.70	54.25
SBM[5]-44	23.71	23.79	26.02	26.11
Barley	26.77	26.08	12.00	11.31
Wheat bran	5.55	5.55	4.07	4.07
Tallow	1.00	1.00	2.00	2.00
MCP[6]	0.62	0.62	0.68	0.68
Limestone	0.80	0.80	0.91	0.91
L-Lysine·HCl	0.14	0.14	0.12	0.12
DL-Methionine	0.00	0.00	0.00	0.00
Threonine	0.00	0.00	0.00	0.00
Vit. Mix[2]	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Lysophospholipids	0.00	0.05	0.00	0.05
Total	100.00	100.00	100.00	100.00
Chemical composition[4]				
ME, kcal/kg	3,200.00	3,200.00	3,300.00	3,300.00
CP[7], %	18.0	18.0	18.0	18.0
Total lysine, %	0.95	0.95	0.95	0.95
Total methionine, %	0.25	0.25	0.25	0.25
Total threonine, %	0.61	0.61	0.61	0.61
Ca, %	0.60	0.60	0.60	0.60
Total P, %	0.50	0.50	0.50	0.50

[1] Treatment L1(3,200 kcal of ME/kg + 0 % LPL), Treatment L2(3,200 kcal of ME/kg + 0.05 %LPL), Treatment H1(3,300 kcal of ME/kg + 0 % LPL), Treatment H2(3,300 kcal of ME /kg + 0.05 % LPL). Lysolecithin content 25% from Kemin Industries.

[2] Vitamin Mix. Provided the following quantities of vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1600 IU; vitamin E, 32 IU; D-biotin, 64g; riboflavin, 3.2mg; calcium pantothenic acid, 8 mg; niacin, 16mg; vitamin B_{12}, 12g; vitamin K, 2.4 mg

[3] Mineral Mix. Provided the following quantities of mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu-SO_4, 54.1mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4] Calculated values

[5] SBM : Soybean meal

[6] MCP : Mono calcium phosphate

[7] CP : Crude protein

Table 2. The effect of dietary energy levels and supplemental LPL nutrient digestibility

Item	Treatments[1]				SEM[2]	P-value		
	L1	L2	H1	H2		Energy	LPL	E X L
Nutrient digestibility, %								
Dry matter	83.28	81.22	83.13	83.10	0.654	0.55	0.48	0.49
Crude protein	76.66	76.18	79.31	79.94	0.901	0.10	0.96	0.76
Crude fat	68.50	70.64	70.12	73.78	1.634	0.49	0.40	0.82
Crude ash	46.23	44.58	45.81	45.66	1.514	0.93	0.81	0.84
Nitrogen retention, g/day								
N intake	11.96	11.85	11.95	11.86	-	-	-	-
Fecal N	2.64	2.82	3.55	3.28	0.170	0.06	0.48	0.88
Urinary N	3.34	2.64	3.33	3.56	0.456	0.72	0.91	0.49
N retention	5.85	6.51	5.59	4.73	3.813	0.33	0.91	0.45

[1]Total of 12 crossbred pigs was fed from averaged initial weight of pigs averaged 22.76±1.6 kg BW.

[2]Standard error of the mean.

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VI. Summary in Korean

본 연구는 LPL(라이소레시친 유화제)을 이유자돈 및 육성전기에 적용하였을 때 에너지 절감효과 및 성적개선 효과를 확인하고 또한 LPL 이 육성전기 소화율에 미치는 영향을 알아보고자 실시하였으며, 그리고, 임신 말기부터 이유까지 임신 및 포유모돈에 각기 다른 에너지 수준 및 유화제를 적용하였을 때 모돈의 성적에 미치는 영향을 알아보고자 본 연구를 수행하였다.

Experiment 1. Energy sparing effects of dietary LPL in weaning and growing pigs

본 연구는 이유 성장 돼지의 성장 성적과 생산성에 LPL 의 에너지 절감 효과를 평가하기 위해 실시되었다. 초기 체중의 7.29 ± 1.62 kg 평균 140 교잡종([요크셔 × 랜드 레이스] × 듀록) 돼지의 총 무작위로 성별에 무작위로 RCB 디자인에 따라 초기 체중에 따라 분류 된 펜당 7 두씩 5 반복으로 하였다. 2 × 2 방식을 사용하고, 제 계수식이 에너지 수준 (ME 3200 또는 3300 Kcal)이고, 두 번째 처리는 LPL (첨가수준 0.05 %)을 보충 하였다. 실험 돼지는 옥수수, 보리 - 대두박을 기초로 사료를 급여하고, 급여프로그램은 세 단계로 구성된다 (단계 I, 0-2 주, 단계 II, 3~5 주, 단계 III, 6~10 주). 단계 I 에서, 평균 일당 증체량 (ADG)과 평균 일일 사료 섭취량 (ADFI)의 유의적인 차이가 관찰되지

않았다. 그러나, 사료효율(G / F)은 낮은 에너지 처리구에 (P = 0.04) LPL 첨가시 높은 경향을 나타냈다. 단계 II (3-5 주간)에서는 에너지 수준 및 LPL 처리구와 관계없이 모두 성장성적에 영향을 미치지 않았다. 단계 III 에서, ADG (P <0.01)와 사료효율(G / F) (P = 0.04)이 LPL 을 사료에 첨했을 때 크게 개선되는 경향이 관찰되었다. LPL 처리구는 각각 5 ~ 10 주와 0~10 주 15 %와 11 % ADG 가 개선되었다. 또한, LPL 처리구들이 5-10 주, 0~10 주 각각 13 %, 20 % 사료효율이 크게 개선었다. 사양시험 단계 II 를 제외한 전체 실험 기간 동안 LPL 첨가된 사료를 공급했을 때 경제성면에서 가장 유리하였다. 따라서, 이 실험은 LPL 첨가로 육성돼지의 성장능력 및 생산성을 향상시켜 생산비용을 절감할 수 있다라는 것을 입증 하였다.

색인어 : LPL, 성장성적, RCB, ADG, 사료효율

Experiment 2. Effects of different energy and LPL supplementation in late gestating and lactating sows.

본 연구는 임신말기-포유 모돈 사료 내 에너지와 LPL의 첨가가 모돈의번식성적, 포유성적, 돈유 품질과 모돈 혈액 성분 그리고 포유자돈

성장성적 및 면역 성분에 미치는 영향과 임신말기-포유 모돈 사료의 LPL 적용 가능성을 규명하기 위해 수행되었다.

사료 내 LPL 첨가로 인한 에너지 이용성 증가는 임신말기 직장 온도를 유의적으로 증가시켰고 ($P<0.01$), 번식 성적과 포유 성적에 유의적인 차이는 나타내지 않았지만, 수치적으로는 이유두수를 복당 0.34두를 증가시켰다. 또한 사료 내 LPL 첨가는 포유자돈성적에는 유의적인 차이는 나타내지 않았지만, LPL 처리구들이 21일령 이유시에 복당 포유자돈 증체량이 수치적으로 평균 6.5% (2.8kg)이 높았다. 분만시에는 복당 산자수 및 체중 그리고 복당 생존율에서 에너지수준과 LPL 첨가 수준에 따른 상호작용이 발견되었다.

포유자돈 21일령에서 LPL 처리구에서 자돈 혈액 내 IgG 수치가 낮았지만 성장성적에는 부정적인 영향을 미치지 않았다. 결론적으로 전체적으로 번식성적과 포유자돈의 성적에는 통계학적으로 유의차이가 나지는 않았지만, 에너지가 높을 수록 그리고 LPL이 첨가되었을 경우 번식성적 및 포유자돈의 성장성적에서 수치적으로 개선되는 차이를 보였다. 따라서, LPL의 모돈에 대한 영향을 연구하기 위해서는 추가적인 실험들이 필요할 것으로 사료된다.

색인어 : LPL, 에너지, 성장성적, 번식성적, 포유성적, IgG

Experiment 3. Effects of dietary LPL supplementation on nutrient digestibility in growing pigs

본 실험은 육성돈 사료내 다른 수준의 에너지 함량 및 LPL 첨가가 영양소 소화율에 미치는 영향을 조사하기 위해서 수행되었다. 총 12 두의 ([Yorkshire × Landrace] × Duroc) 육성돈을 공시하여, 완전임의배치법에 의해 4 처리 처리당 3 두로 체중을 고려하였다 (평균 체중 22.7±1.6kg). 사료는 옥수수-보리-대두박 위주의 기초사료가 이용되었으며, 에너지를 3,200 kcal of ME/k 와 3,300 kcal of ME/kg 로 두 그룹으로 나눈 후 각 그룹을 또 LPL 을 첨가와 무첨가구로 나누었다(2 x 2 factorial). 실험기간내 사료영양은 NRC (2012) 사양표준의 기준을 따랐으며 하루에 2 번 (각 08:00, 20:00) 사료를 급여했다. 소화율 실험기간이 끝난 후 분석결과 건물, 조지방, 조단백 그리고 질소 소화율에는 유의적인 차이를 보이지 않았다. 일반적으로 사료내 유화제를 첨가하면 지방소화가 개선되는 영향이 있다는 많은 보고들이 있다. 그럼에도 불구하고 본 실험에서는 지방소화율뿐만 아니라 다른 영양소들의 소화율에 차이가 없었다. 하지만 같은 수준의 에너지 사료내에서는 LPL 을 첨가했을 경우 지방 소화율이 수치적으로 증가하는 차이를 보였다 (L2, H2). 따라서, 유화제 첨가가

지방소화에 미치는 영향에 대해서는 좀 더 많은 연구가 필요하다고 사료된다.

색인어 : LPL, 유화제, 소화율, NRC, 완전임의 배치법